3233

Not to be issued out

STUDIES ON THE ICE AGE IN INDIA AND ASSOCIATED HUMAN CULTURES

By

H. DE TERRA
Research Associate, Carnegie Institution of Washington

AND

T. T. PATERSON
Cambridge University

3233

PUBLISHED BY THE CARNEGIE INSTITUTION OF WASHINGTON
WASHINGTON, D. C.
1939

CARNEGIE INSTITUTION OF WASHINGTON PUBLICATION NO. 493

JUDD & DETWEILER, INC., PRINTERS
STANDARD ENGRAVING CO.
WASHINGTON, D. C.
A. HOEN & CO., BALTIMORE

CONTENTS

ILLUSTRATIONS

PLATES

(At end of text)

TEXT FIGURES

STUDIES ON THE ICE AGE IN INDIA AND ASSOCIATED HUMAN CULTURES

"The whole geological record is only the skimmings of the pot of life."
—*Thomas Huxley*, in a letter of 1862 to Charles Darwin.

INTRODUCTION

In this report, which deals with the geologic and archeologic results of an expedition sponsored by the Carnegie Institution of Washington, Yale University, Cambridge University, and the American Philosophical Society and carried out in 1935 under the direction of Hellmut de Terra,[1] in association with T. T. Paterson and P. Teilhard de Chardin, an attempt has been made to understand the Ice Age cycle in the Himalaya and to unravel the Pleistocene history of Stone Age man in other parts of India.

For more than a hundred years the Siwalik Hills of northern India have been recognized as one of the chief sources of ancient mammal life. Here, in 1836, Falconer and Cautley attracted the attention of the scientific world to the problem of human origins, through their discoveries of the Siwalik fauna and their announcement of a find of a fossil primate which antedated by one year Lartet's discovery in France. And from Kashmir Godwin-Austen and Richard Lydekker contributed the first evidence of a Himalayan Ice Age, at a time when Agassiz in America was revolutionizing geologic conceptions of past climates. Lydekker had argued that the glaciations of the Ice Age had extinguished the great mammal assemblage of the Siwalik Hills at the end of Tertiary time, yet there had always remained some doubts as to the extent of the glaciations and their impact on contemporary life. The reconnaissance of Himalayan geology and paleontology subsequently carried out by members of the Geological Survey of India brought to light some astonishing data concerning both mammal evolution and the recency of the earth movements that had produced the great mountain chain of the Himalayas. From then on the two phenomena, mountain uplift and human origins, were associated in the minds of many a scholar. Despite this speculative interest, however, it was not generally known that Stone Age implements had occasionally been collected in the foothills and plains of the Punjab by travelers interested in the collecting of data but not fully aware of the important implications of their stray finds. When evidence of Himalayan glaciations finally became part of our assured knowledge, especially through the studies of Theobald, Oestreich, Middlemiss, Grinlinton, and Dainelli, it became evident that Kashmir and the adjoining plains contain all the essential data for a study of the late Cenozoic geology of early man in southern Asia.

One outstanding problem presented itself from the beginning—the geologic relationships between Siwalik and mountain history at the turn of the Tertiary

[1] Except as otherwise indicated, the text of this publication was written by Dr. de Terra.

and during the Pleistocene. My initial finds of Stone Age artifacts in Kashmir and in the Salt Range, by-products of my first explorations of 1932–33, made me suspect the existence of better records of early man—a suspicion which was shared by the late Dr. Davidson Black and by Dr. G. E. Hutchinson, of Yale University, to whom I owe the initial encouragement for my plan. Furthermore, my previous expedition had been successful in collecting a number of new fossil anthropoids from the Siwalik beds, which were subsequently described by Mr. G. E. Lewis. These attracted much attention among students of primate phylogeny. In addition a three months' stay in Kashmir had already given me some sort of outline for the glacial history of the region immediately adjacent to the Siwalik Hills. Accordingly it seemed to me that a multiple study of the geologic, paleontologic, and archeologic history of late Cenozoic time in the sub-Himalayan region would yield results that might prove applicable to neighboring fields of research in Asia.

Acknowledgments.—Very fortunately my plans were favorably received and actively supported by a number of institutions in this country and abroad. To all of them are due my sincerest thanks for the moral and financial support with which they so generously assisted my endeavors.

Foremost among these is the Carnegie Institution of Washington, whose president, Dr. John C. Merriam, gave me the most liberal and sympathetic support.

Through aid from the Penrose Fund of the American Philosophical Society it was possible to achieve the association of Dr. Teilhard de Chardin and to defray expenses in connection with the collecting of fossils and artifacts.

The president of Yale University, Dr. James R. Angell, and members of the geologic faculty granted me leave of absence, for which I am sincerely obliged.

Special acknowledgment is due to the director and various members of the Geological Survey of India for their generous cooperation and especially for their willingness to attach Mr. N. K. N. Aiyengar to my party as collector of fossils. Tireless in his efforts, Mr. Aiyengar was able to gather a remarkable number of Siwalik fossils, including many primates.

The assistance of Mr. D. Sen, M. A., of Calcutta University, was of much help and facilitated contact with local officials.

Mr. J. H. J. Drummond, M. A., of Christ's College, Cambridge, joined the expedition in the fall of 1935 as assistant to my associate, Mr. T. T. Paterson, in charge of certain geologic and archeologic studies. I am most grateful for the sincere interest which Mr. Drummond showed in the work and for his helping hand in the preparation of Mr. Paterson's manuscript.

Mr. Paterson desires to express his gratitude to the following committees and institutions for their generous financial support: Percy Sladen Trust, Royal Society of London, Royal Geographical Society, Cambridge University (Wortz fund), Trinity College, Cambridge.

During the period of field work, Mr. Paterson was in receipt of an Anthony

Wilkins studentship (Cambridge) and, during the period of preparation of results, of a senior studentship from the Royal Commission for the Exhibition of 1851. His enthusiasm, thoroughness, and never-failing cooperation won him the admiration of all the members of the expedition and especially of the leader. On many an occasion I relied successfully on his judgment.

To my friend and collaborator, Dr. Teilhard de Chardin, I owe a great deal of advice and cooperation. The perspicacious application of his great knowledge to this particular field and his judicious views and critical opinions were a constant source of inspiration and encouragement. Many of the Pleistocene fossils and implements were collected by him, and all the culture-bearing sections in the Punjab, central India, and Sind were examined jointly with him. He prepared two brief reports on his observations in India, which he put at my disposal.

During the period of laboratory studies I enjoyed the collaboration of various colleagues. Professor William K. Gregory and Dr. M. Hellman undertook the study of the fossil anthropoid material, the results of which have been published elsewhere.[1] Dr. Edwin H. Colbert, of the American Museum of Natural History, determined the bulk of the Siwalik and Narbada fossils. Dr. R. R. Stewart, principal of Gordon College, Rawalpindi, India, examined the fossil-plant material from the Karewa beds of Kashmir. Unfortunately it has not been possible to give a more descriptive account of this interesting fossil flora, but it is hoped that such an account may be prepared in the near future. Mr. P. S. Conger, research associate of the Carnegie Institution of Washington, determined the diatoms from various Pleistocene sediments, and Dr. Paul D. Krynine, of the School of Mineral Industries of Pennsylvania State College, made the petrologic analyses of the Quaternary eolian and lacustrine deposits.

To all the men above named I express my sincerest appreciation for their readiness to cooperate.

Collections.—Owing to the scattered investments and interests in this expedition it was necessary to divide the collections among various institutions. The artifact collection was split into three principal divisions—one-third to the Peabody Museum of Natural History of Yale University, one-third to the Archeological Museum of Cambridge University, England, and one-third to the Archeological Survey of India.

Of the Siwalik fossils the anthropoid specimens were divided equally between Yale University and the Geological Survey of India, and so was the bulk of the paleontologic material, with the exception of such specimens as had never before been described. These were kept in the collection of Siwalik fossils in the American Museum of Natural History.

The fossil plants are still in the hands of Dr. Stewart, who continues to collect every summer from the Karewa beds in Kashmir.

[1] W. K. Gregory, Milo Hellman, and G. E. Lewis, Fossil Anthropoids of the Yale-Cambridge India Expedition of 1935. Carnegie Inst. Wash. Pub. No. 495, 1938.

Brief itinerary of field work.—I started into the field in the beginning of March 1935 and spent one month collecting with Sen in the Siwalik beds and Pleistocene formations of the central and northern Salt Range near Naushahra, Kanatti, and Chinji. In April we investigated the Soan Valley of the Potwar region near Rawalpindi and were joined on April 18 by Paterson.

In May Paterson began his glaciologic studies in the Sind Valley of Kashmir, while Aiyengar began his fossil collecting in Jammu. I contracted typhus and

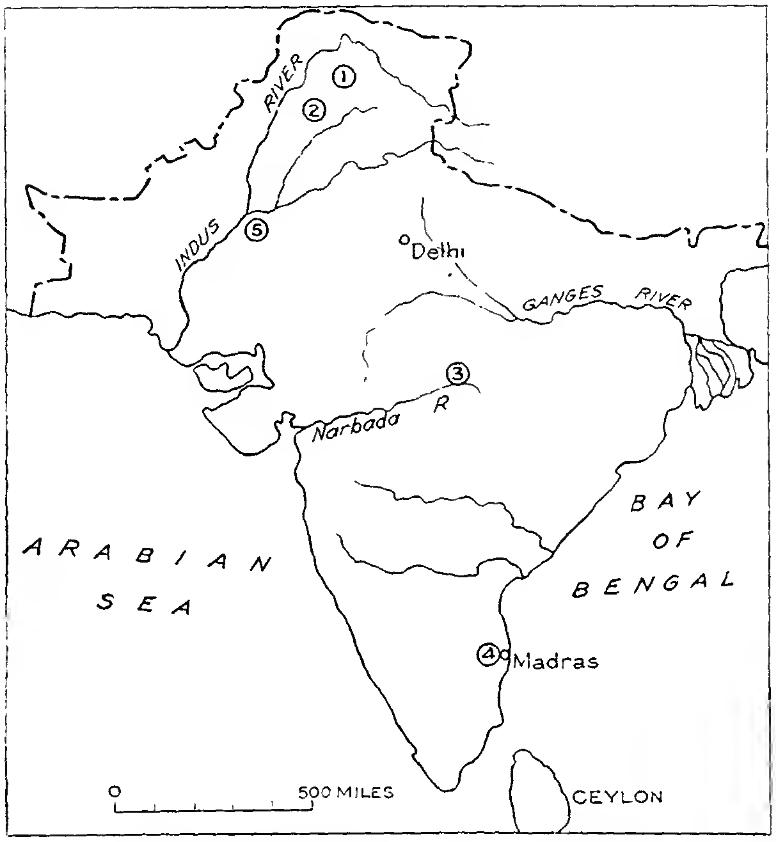


FIGURE 1.—Index map showing location of the five areas with which this report is concerned. 1, Kashmir; 2, Potwar-Indus (northwestern Punjab); 3, Narbada Valley near Hoshangabad and Narsinghpur; 4, Madras; 5, Sukkur and Rohri, upper Sind.

was laid up until the end of June, when I continued the geologic survey of the Kashmir Valley begun in 1932. After having extended his studies into the Liddar Valley, Paterson made a traverse across Pir Panjal to Poonch and remained in the foothills between the Poonch and Jhelum valleys until the end of September. Except for a three weeks' tour to Jammu and Ramnagar I worked on the northeastern slope of Pir Panjal until September 25. During this time Sen made a general survey tour of the caves in Kashmir, and Aiyengar collected in the Salt Range.

At the end of September Dr. Teilhard joined us in Srinagar, Kashmir, where we made several excursions to exposures of glacial features and terraces. By that

time our party had been increased by another Indian member, Mr. Krishnaswami, of Madras, who first accompanied us across the Salt Range and into the Soan Valley and later went with Paterson to the Indus region. From Rawalpindi, our temporary expedition headquarters, various excursions were made into the Potwar and Indus regions. Aiyengar concluded his collecting activities at Haritalyangar, Bilaspur State, which is one of the major localities for fossil primates.

Paterson, who had been joined by Drummond in October, wound up his field work in the Punjab around November 1 and proceeded to Calcutta and finally Madras, visiting on his way various museums for the sake of their collections of Stone Age tools. The last weeks of his stay in India were devoted to the terrace geology and archeology of the region near Madras.

Dr. Teilhard and I made a brief tour to the lower Indus region near Sukkur and visited the famous ruins of Mohenjo Daro. At the end of November we proceeded to the Narbada Valley, in central India. Here we spent 2 weeks in studying the Pleistocene alluvium. By the end of December the field work was terminated, and shortly before Christmas the various members of the expedition departed from Bombay and Calcutta.

Explanatory note concerning this publication.—Owing to the regional division of this field work the report has two main divisions, the second consisting of four smaller parts; the first main division, part I, deals with the Ice Age in southwestern Kashmir, and the second, parts II to V, with our Pleistocene and archeologic studies in other parts of India. This arrangement will permit the reader to become acquainted first with the glacial cycle in the Himalaya—knowledge which in our opinion is fundamental to an understanding of the Pleistocene stratigraphy of the adjoining plains. I had chosen two of the important Himalayan valleys, Sind and Liddar, for a special glaciologic survey, which accounts for the large space devoted to their description. The separate laboratory studies carried out in the Academy of Natural Sciences at Philadelphia and in the Archeological Museum at Cambridge, England, made neither for an even style nor for uniform presentation, but this was a situation which could not be avoided in view of the conditions imposed after my return from India. Wherever there is a disagreement of interpretation, and the reader will not discover many, a special footnote has been inserted which gives a considered opinion.

It is hoped that this volume will contribute to an understanding of Pleistocene geology and prehistory in Asia and that it will generally encourage the development of a border science in which geologist and archeologist join in a cooperative study of human evolution on a geologic basis.

Figure 1 shows the location of the five areas studied.

Part I. THE ICE AGE IN SOUTHWESTERN KASHMIR

A. GEOGRAPHIC AND GEOLOGIC ASPECTS OF THE REGION

The area studied comprises the larger portion of southwestern Kashmir and may be defined as lying between the central Himalayan Range and the Punjab plain as approximately outlined by 73°40′ to 76° E. and 32°30′ to 34°30′ N.

From the barren gravel-strewn lowlands between the Chenab and Jhelum rivers (pl. I, 1) the topographic surface rises quickly to high forest-clad foothills, 6,000 to 8,000 feet above sea level. Deeply dissected and covered with vegetation of a temperate climate, this country reminds one somewhat of the foothills of the northern Alps or of certain portions of Scotland. Yet its Indian character is unmistakable. The diversity of races among its inhabitants, with their traditional complexity of religious creed; the curious blend of tropical plants, such as mango, banana, and palms, with pine-oak forests; the cultivation of rice and millet; and countless other features remind the traveler that this is the fringe of India's plains toward the Himalaya. Through magnificent forests of pine, cedar, fir, and spruce the roads wind their courses toward the watershed of the Pir Panjal. This first sub-Himalayan mountain barrier rises 15,000 feet high and separates the plains country from the Kashmir Valley. With a total length of 150 miles and an average width of 65 miles, the Pir Panjal ranks second in importance to the still higher slope of the Himalayan Range in the northeast. Patches of paper birch, juniper, and rhododendron cling to the rocky, weather-beaten heights of the Pir Panjal, but above 12,000 feet no trees exist. Alpine meadows, the "margs" of the natives, cover the rolling upland and on them the "gujars," the Kashmir herdsmen, live all summer long with their flocks of sheep, goat, and water buffalo. Glaciers are few and are localized at the highest culmination of the relief around Tatakuti (15,500 feet) and Lake Konsa Nagh, yet deep cirques and large trough-shaped valleys testify to the extent of previous glaciations, traces of which are found along the mountain slopes (pl. I, 2). From the crest of the Pir Panjal the view extends across the huge bowl of the Kashmir Valley, with its lake and winding river, northeastward to the great Himalayan Range, whence rises the giant mass of Nanga Parbat (26,620 feet) like an island above a sea of rocky snow ridges.

Down the northern slope the roads lead through deeply entrenched valleys, and for over 10 miles fir forest with thick underbrush of arrowwood, skimmia, rose, and barberry covers the mountain flank (pl. I, 3). Toward the valley outlets the forest is rapidly replaced by cultivated tracts, and at an altitude of about 7,000 feet fields of maize and rice appear, cleverly irrigated and watered by clear mountain streams. High terraced foothills, the so-called "karewas" of the Kashmiris, slope gently to the valley, into whose level they merge at about 6,000 feet. In this region up to 7,500 feet, deodar cedar, pine, and walnut mingle with poplar, willow, elm, and horse chestnut, and in the undergrowth thrive hazel, witch alder,

and wild indigo. Over its entire width of 25 miles the valley is cultivated, and by its fertility it has through the ages given bread and culture to its industrious people. This cultivation, especially of rice, corn, and mulberry trees, extends deep into the valleys of the Himalayan slope until rocky gorges and icy winds block further advance (pl. I, 4; pl. III, 2). Here, then, is the limit of the temperate, humid region, and as the traveler crosses the high Himalayan Range toward Indian Tibet, he finds that the alpine and semiarid desert of Central Asia begins.

Thus, in a geographic sense, southwestern Kashmir has all the characteristics of a "border land" between peninsular India and high Asia, and its physiographic divisions accordingly range from lowland to high alpine mountains.

PHYSIOGRAPHIC DIVISIONS

Physiographically the area under discussion may be divided into five parts—the narrow belt of plains country in Jammu and Poonch; the convex arches of the foothills between the Poonch and Ravi rivers; the Pir Panjal; the Kashmir Valley Basin; and the southern slope of the main Himalayan Range. The altitude ranges from 850 feet to more than 20,000 feet above sea level (fig. 3). Good topographic maps on a scale of 1 inch to a mile with 100-foot contours give a complete survey of the topography and afford insight into all the details of the relief and its morphologic peculiarities.[1]

Plains country.—The southwestern division, the plains country, presents a narrow stretch of hilly lowlands, some 10 to 16 miles wide, and rises gently from about 850 to 2,000 feet above sea level. Being the present level of erosion for the adjoining mountain drainage system, it is composed of large fans across which the rivers discharge their sedimentary load to the Punjab plain. Between the fans remnants of Tertiary and Pleistocene rocks surmount the plain in the form of isolated hillocks and hilly ridges, and a well-dissected mantle of Pleistocene loess and loam extends locally for miles from one valley slope to the other. The orographic strike of these lowland ridges is generally northwest to southeast and is in accordance with the geologic extension of the shallow folds that emerge from underneath the younger formations. In addition, particularly in the plains between the Jhelum and Chenab rivers, there are low "swells" in the relief, which are shallow anticlines of Pleistocene formations. They are hardly perceptible to casual observation, as they surmount the plains level by some 100 feet only, but they are distinctly significant in a geographic and geologic sense. Their origin is structural, as their anticlinal nature reveals, and their physiographic appearance at the base of the foothills would indicate that they are young folds in the making. They are already dissected along the anticlinal axes, and much of this initial drainage takes its origin from a superposed badland topography developed in the soft loess or loam beds on top.

Through these lowlands the rivers generally flow with broad, somewhat incised meanders (pl. I, 1), and the largest streams, such as the Chenab and

[1] Places mentioned in the text but not shown on the maps will be found on the ¼-inch maps of the Trigonometric Survey of India.

Jhelum, proceed across their own gravel fans. Their gradient is still remarkably steep compared with that of certain preglacial stream courses.

Foothills.—From the sun-baked plain the foothills rise in longitudinal ridges 2,000 to 3,000 feet high. Behind these front ridges there extends generally a turbulent sea of variegated badlands, in which the Tertiary Siwalik beds exhibit a multitude of colors, mainly red, orange, and gray. Beyond this colorful desert landscape rise steep mountainous ridges and spurs in which the foliage of underbrush and the dark shades of pine forests conceal the vivid red of the Miocene Murree formation. The high ridges and interstream divides extend up to 7,000 feet, and although dissection is intense, their heights display unmistakable signs of an older topography. Leveled spurs and plateau remnants, relics of wide valley flats and abrupt terminations of high valley floors along master streams, indicate a mature relief which underwent rejuvenation.[1] The magnificent view from Murree eastward, where the sky line displays long sloping spurs, or the panorama above Chineni, in Jammu, with the evenly inclined crest level of sandstone ridges, bears witness to an ancient slope topography. Closer study, however, shows that this relief is not so uniform as a bird's-eye view might lead one to suppose. There are precipitous cliffs, the scars of fault movements, or promontories of resistant rocks. There are also at least two levels of elevated valley flats or terraces and correspondingly two bench levels on the ridges, indicating two stages of peneplanation and an intervening period of mature dissection. A major break in this relief is apparent along the great thrust fault between Murree (Miocene) and Eocene rocks in the Chenab Valley near Ramban. Fault-line scarps also line the northern rim of the basin at Udhampur (pl. XXIII, 2). It is clear, then, that these fault scarps are of younger date than the mature relief, a deduction fully in accord with the geomorphologic analysis presented in the succeeding section.

The valleys are terraced and deeply incised except where they enter an intermediate basin, as at Udhampur, or at Poonch, where they are entrenched in gravel-filled basin flats. Locally their courses may temporarily be deflected by landslides, which are very common in the foothills, as the valley slopes are constantly undercut by rapidly eroding streams. The valley gorges of the Jhelum below Domel and of the Chenab above Riasi, with their chasms 6,000 feet deep, illustrate the magnitude of this process. Skillful engineering has laid automobile roads through these natural entrances to Kashmir, but the maintenance cost, due to constant sliding and catapulting of rock masses, has already exceeded the original cost of construction.

The Pir Panjal.—From Domel southeastward to the Chenab River at Kishtwar the Pir Panjal ("rocky range") makes the first mountain rampart within the Himalayan belt. Viewed on a relief map, it is seen as but a sub-Himalayan range at the foot of the main or central Himalaya, whose mountain giants look down on their smaller southern neighbor by more than 10,000 feet. And yet the Pir Panjal by itself forms an impressive unit of mountains whose average crest level lies about 12,500 feet above the sea. The peaks Tatakuti and Brama Sakul (15,523

[1] This was described by Oestreich (1906), who analyzed this area as an uplifted peneplain with antecedent drainage. (See "Literature references," at end of text.)

feet) mark its highest points, the latter rising as a snow-capped group of five summits above the lowland of Poonch and Punjab. Between these two culminations, the watershed is about 13,500 feet high, but beyond, toward the Jhelum and Chenab rivers, it lowers itself perceptibly by 3,000 to 4,000 feet.

The crest or watershed proper abounds with rugged peaks and crevassed slopes in which large lake-filled cirques, firn and glacier basins, and wide valleys make for a true alpine landscape (pl. I, 2). Between the valley heads lie long leveled divides indicative of a mature land form, dissected by streams and ice. The southwest slope is much more rugged and more fully dissected than the northeast slope, owing, no doubt, to the steepness of the southern slope and to the monsoon expo-

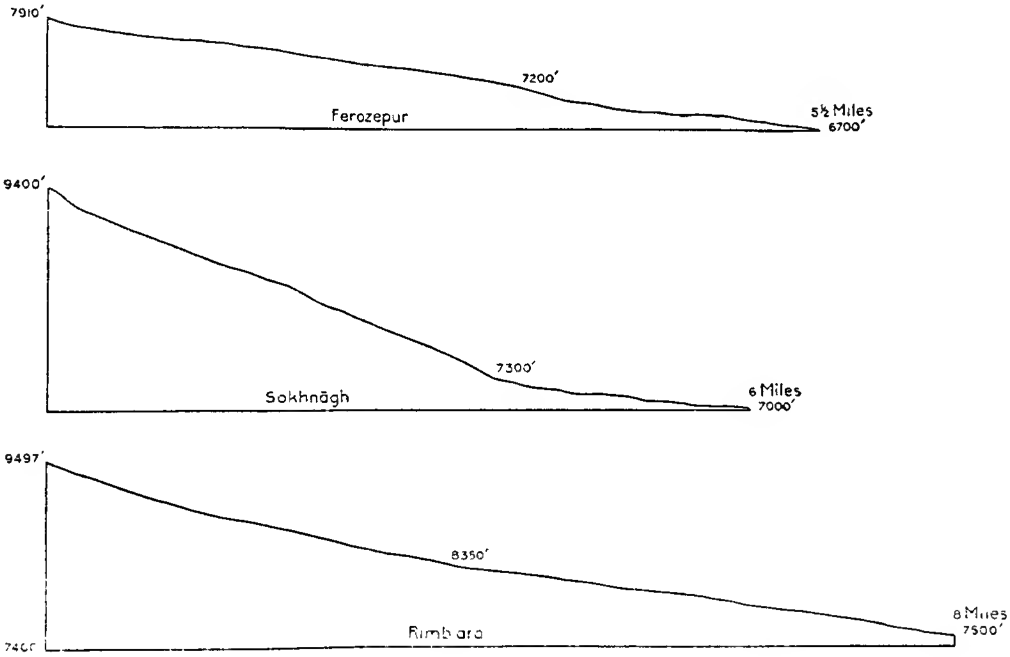


FIGURE 2.—River gradients on the Kashmir slope of the Pir Panjal.

sure. (See p. 11.) The highly elevated groups of summits are built of hard igneous rocks, but so are portions of the adjoining leveled spurs and plateau remnants. These relationships substantiate the evidence, previously cited, for the presence of a mature relief, and they suggest that the Pir Panjal peaks originated from an older range or ridge which was incompletely consumed by a process of peneplanation of preglacial date.

Traces of this mature relief extend all along the higher slopes and are discussed in a subsequent section. This rolling upland makes a kind of shoulder on the northeastern flank of the range at about 13,000 to 12,000 feet, when it drops abruptly to 9,000 feet or so (fig. 8). Here begins the steeply sloping and forested stretch of the "karewas" with their softly rounded divides and steeply inclined surfaces (pl. I, 3). This is the foothill region of the Pir Panjal toward Kashmir. Veiled by a soft mantle of Pleistocene lake beds, it contrasts remarkably with the

precipitous corresponding slope of the range. The rivers are strongly incised, yet not so deeply as along the southeastern flank, and their stream levels lie normally some 1,500 feet deeper than the slope surface. Wherever the Pleistocene deposits are stripped away or otherwise missing, the relief is much more abrupt and even precipitous, as for instance along the road to Banihal Pass. As figure 2 shows, the streams become more graded as soon as they reach the mountain border proper, which generally coincides with the boundary of the Pleistocene lake beds.

A peculiar physiographic feature on this slope are the "karewas," the tilted, generally dissected surfaces of the Pleistocene Karewa lake beds. Parallel drainage has produced their long, evenly inclined ridges and spurs, which give the impression of a uniform tilted terrace level. A profile (fig. 77) from the Kashmir Valley to the high Pir Panjal shows that these surfaces start as horizontal terraces, turn into dip slopes along the northeastern limb of the first anticline, and then break up into a dissected relief which is superimposed on the preglacial rock floor. On page 98 it is shown that the "karewa terrace" above the Jhelum is a constructional surface derived from the initial floor of the Pleistocene lake. The dissected and tilted surface of the Pir Panjal slope is therefore the result of an evenly proceeding denudation on a tilted and folded mass of silt and lake clay. Proof of this statement is found in the tilting of the topmost terrace level on the first anticline, the relationship between ridges and anticlines, valleys and synclines, as shown by the relief of Yus Maidan (see pl. LV) and the absence of terrace gravel on the Karewa surfaces. These levels, therefore, cannot be interpreted as fluvial terraces of a meandering Jhelum stream which suffered tilting, as Dainelli (1922) and Huntington (1906*a*) thought, but they are dissected and tilted remnants of the ancient lake floor. Below this dissected surface there are, however, true terraces, which are discussed in their appropriate places. At this point it must suffice to mention that there are locally two rock benches, one at about 8,800 feet, the other at 8,000 feet. They become conspicuous at the outlets of major valleys, as above Tangmarg or in the Jhelum gorge below Baramula. Such benches are preglacial terraces in the rock floor, veiled by lake beds, which faithfully reproduced the underlying topography. Owing to this mantle of lake beds and younger loess deposits, the mountain streams debouch not at the foot of the "karewas" but along the mountain front, for it is here that the soft clays allow them to get graded at once. These valley outlets lie between 7,100 and 7,300 feet above the sea, or more than 1,000 feet above the level of the Kashmir Basin proper.

Kashmir Valley.—Like a great boat-shaped bowl, the Vale of Kashmir lies perched high at the foot of the main Himalayan range (pl. II, 1; also pl. LV). It covers an area of a little over 2,000 square miles at an average altitude of some 6,000 feet. Physiographically, it is of curious composition, because of its asymmetric build. A transverse section (fig. 3) shows it to have a slant of 2,100 feet over a distance of 25 miles from the Pir Panjal to the Himalayan slope. Its deepest portion lies along the Jhelum River (5,260 feet), whose course, significantly enough, runs along the rocky spurs of the northeastern flank. This abnormal position of the master stream in relation to the basin also causes a striking difference in level

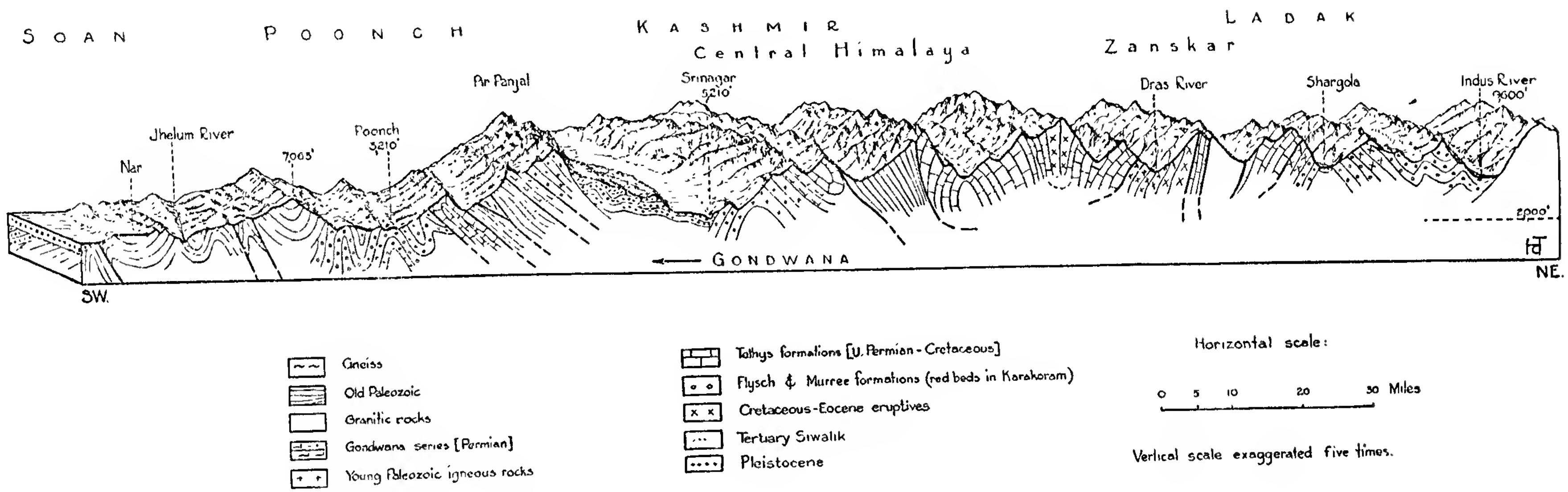


FIGURE 3.—Block diagrammatic sketch of the northwestern Himalaya.

between the valley outlets on the corresponding flanks of the basin. The entire Pir Panjal drainage, except for the Jhelum, enters the basin at about 7,100 feet, whereas the Himalayan streams enter the valley at 5,300 feet. This naturally causes relief making on the Pir Panjal side, as the photograph (pl. II, 1) illustrates. Apart from being terraced, the lower karewas show undulations or "swells" similar to those in the plains country. Such an undulation is noticeable on the great Karewa surface 2¼ miles east of Pulawom, where there is a flat anticline whose limbs slope 4° NE. and 7° SW. To the right of the Jhelum the flats slope away from the mountains (pl. II, 3). Broad fans emerge from the valley outlet along this flank, and there the Sind and Liddar rivers deposit great loads of sand and gravel.

Morphologically interesting are certain isolated high hills and ridges in the Karewa relief. Most of these rise over 1,000 feet above the valley and consist of a core of trap rock mantled by Pleistocene beds. From the Himalayan side project long rocky spurs, some of which have been transformed into isolated mountains, such as Takht-i-Suleiman, above Srinagar (pl. XI, 2, 3).

Lakes and swamps occupy much of the northwestern part of the valley. Lakes Wular, Manasbal, Ankar, and Dal lie in the flood plain of the Jhelum, whose broad meanders have cut swampy lowlands out of the Karewa terraces (pl. XII, 1). This position of the lakes shows that they are derived from enlarged oxbows and abandoned flood channels rather than from progressive shrinkage of a glacial lake.[1] Obviously the crustal instability of this region promoted shifting of the Jhelum course throughout the ages, and abrupt changes in the relief of the valley might have led to a rather sudden shifting of stream channels. The asymmetric position of the Jhelum in the valley alone is proof for the shifting of its channel, promoted by strong uplift of the southwestern flank. This event also doubtless accounts for the asymmetric position of the lakes.

Himalayan slope.—With steep divides and precipitous slopes, the Himalayan range rises above the valley. The peaks of Haramukh (16,000 feet) and Kolahoi (17,799 feet) make prominent glaciated outposts of the high range. The average height of the slope is about 14,000 feet. Although the Himalayan flank bears extensive remnants of mature land forms, no stretches of compact plateaus or peneplain levels are preserved. Complete dissection by streams and glaciers has given this landscape a truly high alpine appearance, especially around the headwaters of the Sind and Liddar streams. In an earlier report (1935) I have sketched the geomorphologic aspect of this Himalayan slope, and at that time a physiographic division in the vertical was introduced in order to elucidate the range of geologic processes involved in the relief making. The units were high massifs, an alpine summit level, lower remnants of a preglacial mature topography, and a lower youthfully eroded valley system. All these units extend across the northeastern portion of our territory. A more detailed description of each of them is given at the proper place in the following chapters.

Orographically, the Himalayan flank presents a peculiar arrangement (pl. LV). In the north there is a curved watershed, some 12,000 feet high, between the

[1] This view has already been expressed by Dainelli (1922), who discussed the origin of the lakes at some length.

upper Jhelum and Kishenganga rivers. This range bends from a southwest-northeast course eastward and finally joins with the southeastward-striking Himalayan Range, whose northwestern portion repeats the same bend. This obviously signifies the critical area of structural syntaxis at which the Himalayan Range ends, as is discussed below. The watershed toward the Chenab also is a ridge sculptured from the main Himalayan range, but its strange north-south strike and its ultimate junction with the Pir Panjal slope make it an even more

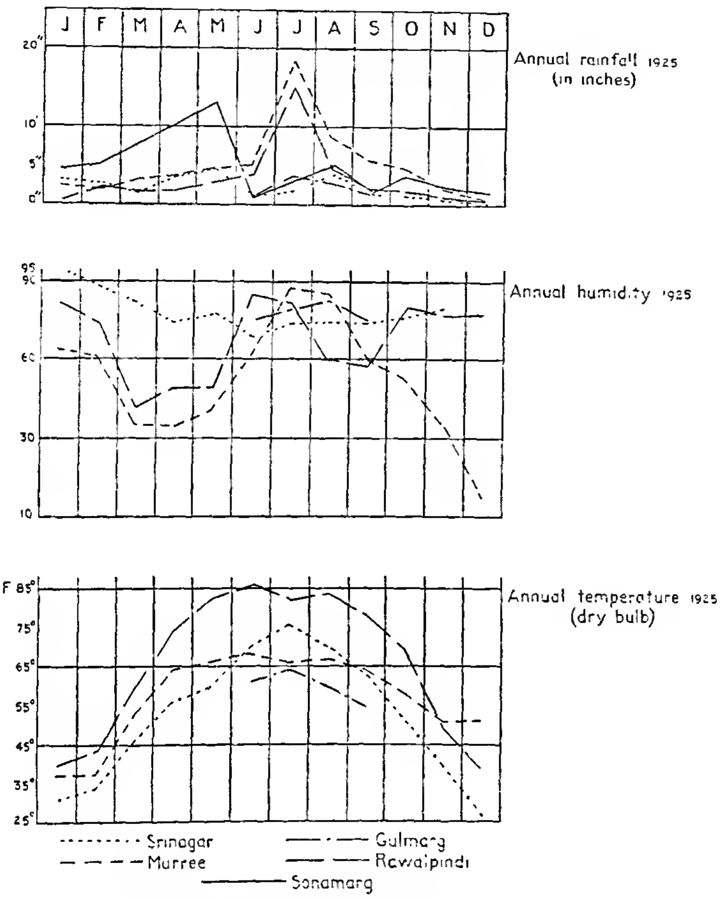


FIGURE 4.—Climatic conditions of Kashmir in regard to rainfall, humidity, and temperature.

puzzling feature than the Kishenganga watershed. On the Banihal Pass its crest is as low as 9,290 feet. Obviously the significance of these physiographic characters cannot be understood without knowledge of the two main relief-making factors, climate and geologic structure.

THE CLIMATE OF KASHMIR

In the introductory section on the geography of this region the temperate climate indicated by the character of its flora is mentioned. Indeed, no other feature is so expressive of Kashmir's climate as the rich forest belt which covers the flanks of both the Pir Panjal and the Himalaya.

The climatic conditions now active in southwestern Kashmir become clear from figures 4 and 5. These diagrams have been computed from data published annually in the official reports (Indian Weather Review) of the Meteorological Department of the Government of India, which represent, so far as I know, the only basis for a brief climatic survey of this area. For this purpose it was held advisable to select the data for such stations as would give a climatic cross section from the plains country in the southwest across the Pir Panjal and the Kashmir Valley to the Himalayan slope. Unfortunately, there are only four meteorologic stations in this region, and of these only two afford complete annual records. These are Jammu (1,029 feet) and Srinagar (5,200 feet); of the other two, Sonamarg (8,750 feet), in the Sind Valley, appears to register the annual rainfall only, and Gulmarg (8,569 feet), in the high Pir Panjal, keeps temporary records from June

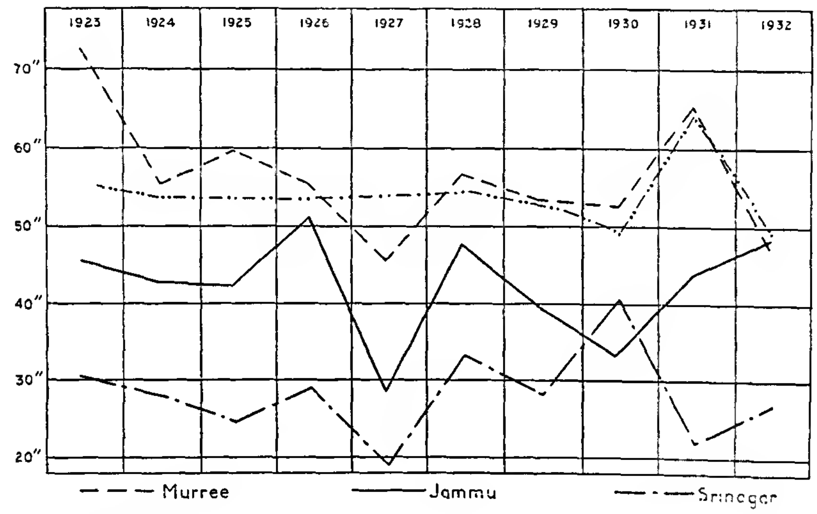


FIGURE 5.—Annual rainfall, 1923–1932, as compared with annual temperature (stippled line).

until September. Thus it was necessary to supplement this rather scanty supply of data by records from two stations, situated across the Kashmir border but within country of the same type. These are Murree (6,181 feet), the "hill station" on the southwest slope of the Pir Panjal, and Rawalpindi (1,689 feet), in the Punjab plains (fig. 6). Their records are of especial interest, as Murree is favorably situated on the monsoon side of the Pir Panjal, and Rawalpindi provides a welcome checking of the records given by the plains station at Jammu.

According to the special need of the meteorologic data in regard to physiographic and geologic conditions I computed in figure 4 records of mean monthly temperature (dry bulb), rainfall, and humidity for the year 1925. Figure 5 shows the records of rainfall for a period of 10 years (1923–1932) as registered by the stations at Jammu, Murree, and Srinagar. The stations are distributed as follows: Jammu and Rawalpindi in the plains, Murree and Gulmarg on corresponding slopes of the Pir Panjal, Srinagar in the Kashmir Valley, and Sonamarg at the foot of the high Himalayan Range.

A glance at the Indian weather map reveals that southwestern Kashmir falls within reach of the monsoon tracts. The southwest monsoon travels from the Bay of Bengal and southwest India along the Himalayan foothills and reaches our region in June. The full impact of this event is revealed in figure 4, which shows the maximum rainfall recorded by Murree, with over 18 inches during July. On the lee side Gulmarg recorded for the same month only a little more than one-sixth of this amount, and Srinagar a maximum fall of not quite 4 inches in August. Thus the Pir Panjal acts as an effective barrier to the monsoon advance, so much so that Srinagar had an average yearly rainfall of some 28.5 inches, while Jammu, in the plains, received 42.25 inches (fig. 5). Accordingly humidity increases during the summer, but the maximum is reached not on the monsoon side but over the Kashmir Valley during January. This phenomenon is evidently dependent on the cool air resting over the valley during the winter and becoming charged with moisture derived from winter rains. These rains are carried into the region from the northwest and southwest by wind currents that advance from the Arabian Sea across Baluchistan, causing showers during January and February. From the annual rainfall curve for Sonamarg, it would seem as if the Himalayan slope received its maximum precipitation in May. As the amount of rain decreases here during the monsoon period proper, it is evident that this rainfall is due to different air currents, which possibly belong to an earlier monsoon advance whose tracts lie in higher regions.

Unlike precipitation, temperature is largely dependent on altitude above sea level, which causes the plains to have a maximum temperature in the shade of over 100° F. during the summer, while at Murree it rarely reaches 80°. Freezing temperatures are common in all areas between 4,000 and 7,000 feet from November until February, and naturally the higher tracts, such as the Pir Panjal and the Himalayan slope, experience winter conditions half the year around. Periods of snow melting vary in the different divisions according to altitude and exposure. On the monsoon side the snow melts rapidly in the Pir Panjal from March until May, but on the Kashmir slopes, in regions higher than 9,000 feet, it stays until June. Accordingly, the Himalayan slope witnesses its greatest snow melting in May and June, with variations caused by differences in the amount of snow or rainfall during May. These rains often lead to destructive inundations of the valley, which spread rapidly from the Jhelum River to the adjoining flood plain and swampy marshes. A single cloudburst in July, 1935, caused the river level to rise 11 feet and almost interrupted all communications with Srinagar, the summer capital of Kashmir. A similar event, yet of larger proportion, may have inundated the valley in prehistoric times and given rise to the Kashmir flood saga as recorded in the "Rājātārāngini," the Sanskrit chronicle of the kings of Kashmir.

Apart from such climatic differences as are determined by physiographic and atmospheric conditions, there are certain variations of climate which are of a more regional nature. Figure 5 shows variations of rainfall over a 10-year period characterized by excessive deficiency of rainfall in 1927 and an excessively

rainy year in 1931. Such climatic variations may not be of great importance to the casual observer, but they are of great geologic significance. For just as the dry annual intervals between the winter and monsoon rains make for conditions favorable to rock decay and wind transport, so do the drier years cause variations of weathering and erosion. These variations must obviously exert their influence on physical geologic forces now active in this region.

According to the monsoon tracts winds blow from the northwest, west, or southeast—that is, in the Kashmir Valley at Srinagar, where wind records are available. Storm conditions of cyclone character arise here at the height of the monsoon, in July, and add to the destructive force of swollen rivers and high lake levels. In April and May thunderstorms advance from the plains or from over the valley and develop high wind velocities. The monsoon winds are guided by morphologic depressions, such as the Kashmir Valley and the transverse gorges of the Pir Panjal slope. These depressions act like "wind funnels," admitting the southeast winds into the mountains, whence they finally sweep into the valley by way of certain low regions or passes. One of these is the Banihal Pass, another the Tosh Maidan plateau, and another the Jhelum Gorge. It is to this southern wind that Kashmir owes some of its attractive features—for example, the dense forest on the northeast slope of the Pir Panjal and the fertility of the valley alluvium. It is difficult to explain the equal density of coniferous woods on both flanks of the Pir Panjal, with its unequal distribution of rainfall, unless a great amount of wind pollination takes place by which pollen is carried annually from the southwestern slopes to the corresponding mountain flank. In the same way the silt, suspended in the dry air over the plains, is carried seasonally across this barrier and dropped over the Kashmir Valley, causing an accumulation of fertile soils.

Botanic Aspect of Climatic Boundary

To the monsoon climate also the flora of the Pir Panjal owes its wealth in species and its ecologic peculiarities. The zonal arrangement of plants especially is significant in view of the previous changes of flora introduced in the course of the climatic and morphologic history, as recorded in fossil-plant beds. On the northeastern slope of the Pir Panjal the following zones can be recognized:[1]

1. *Alpine zone*, above the coniferous forest from about 12,000 to 13,500 feet, with *Juniperus communis* L. and *Juniperus squamata* Buch.-Ham. covering the rocky slopes. The meadows are often full of turf, and along brooks flourish patches of alpine flowers with dwarf willows and honeysuckle, also *Rhododendron anthopogon* D. Don.

2. *White-birch zone*, above the coniferous forest, generally between 10,500 and 12,000 feet. White or paper birch, *Betula utilis* D. Don, is commonly found in pure stands up to about 12,000 feet. It is associated with *Rhododendron campanulatum* D. Don, *Pyrus foliolosa* Wall., *Salix denticulata* Anders., *Syringa emodi* Wall., and *Lonicera* sp.

[1] Dr. R. R. Stewart, principal of Gordon College, Rawalpindi, kindly furnished this brief outline of the plant ecology.

3. *Coniferous-forest zone*, above 7,000 feet, covering both the higher "karewa" surfaces (clay) and the rocky slopes up to 10,500 feet. The dominant tree is the fir, *Abies pindrow* Spach, which in many places forms a pure coniferous forest up to 10,500 feet. *Pinus excelsa* Wall. is the next commonest tree, with a good deal of *Picea smithiana* Boiss. and *Taxus baccata* L. Occasionally, there are specimens of *Prunus cornuta* Wall., *Acer caesium* Wall., *Crataegus oxyacantha* L., *Aesculus indica* Colebr., and *Juglans regia* L. The undergrowth is made up mainly of *Viburnum nervosum* D. Don, *Skimmia laureola* Sieb. et Zucc., *Rosa macrophylla* Lindl., *Ribes* sp., *Berberis* sp., and *Lonicera* sp.

4. *Kashmir Valley zone*, below 7,000 feet, comprising the "karewas" with the following indigenous trees and shrubs: *Cedrus deodara* Loudon and *Pinus excelsa* Wall., on ridges; *Juglans regia* L., *Populus ciliata* Wall., *Salix wallichiana* Anders., *Ulmus wallichiana* Planch., *Celtis alpina* Royle, *Morus serrata* Roxb., *Fraxinus excelsior* L., *Parrotia jacquemontiana* Decne. (usually gregarious). The chenar, *Platanus orientalis* L., *Morus alba* L., *Populus nigra* L., and *Populus alba* L. are probably not indigenous. Oak is entirely absent from the valley, but it occurs at many places on the southwestern slope.

The same ecologic aspect is found on the Himalayan slope, with some variations, but nowhere is the zoning of the Kashmir flora so outstanding as on the Pir Panjal.[1] This fact is of importance with regard to the shifting of vegetation zones during the preceding Ice Age. Indeed, the interpretation of the paleobotanic records found in the early Pleistocene interglacial lake beds and the important implications arising from it cannot be understood without knowledge of present-day plant ecology in Kashmir.

It is obvious that our region owes its climatic conditions mainly to an interplay between the monsoon-swept area and the mountainous tract. In this process the Pir Panjal acts as a barrier to the rain-bringing winds, which precipitate their moisture owing to the high altitude. Therefore, it can be said that the climate of Kashmir is to a large degree dependent on the altitude of the Pir Panjal, and that any lowering of its level in previous times must have brought about an extension of the monsoon influence to the slope of the high Himalaya.

BRIEF OUTLINE OF GEOLOGIC STRUCTURE

Kashmir's position within the Himalaya Mountains is determined by two important geologic features—its location on the margin of a young mobile mountain belt and its proximity to a structural syntaxis. The first feature characterizes it from the very outset as unstable ground, liable to profound crustal disturbances and geographic changes; to the second feature are partly due the orographic outlines of the Kashmir Valley Basin. To understand this relation it is necessary first to review briefly the geologic structure of southwestern Kashmir, the region with which this report is concerned.

[1] Meanwhile the German Nanga Parbat Expeditions have gathered more complete data on the geographic distribution of plant assemblages on the slopes of Nanga Parbat. In contrast to the Pir Panjal the flora depicts a much more arid type of climate, reminiscent of Central Asia (see C. Troll, 1938).

Here physiographic units coincide for the most part with structural divisions or zones. The narrow strip of lowland in the southwest represents the northern margin of the Punjab plains into which the Himalayan rivers, such as the Jhelum, Chenab, Tawi, and Ravi, drop their sedimentary load. This, then, is the sedimentary collecting basin of our time. Primarily endowed with a sinking tendency, this region experienced the tectonic onslaught of the sub-Himalayan folds, which, as has been demonstrated by previous students, led to shallow folding and uplift of Pleistocene formations. Low anticlinal ridges and intermediate synclines give this area the aspect of a fold belt in the process of formation. The relief generally expresses this youthful structure plastically along the border of the foothills, where the Upper Siwalik formation (Pleistocene) forms long strike ridges that surmount the plains by 1,500 feet or more.

In the foothills proper, up to a line between Palandu, Kotli, Ravi, and Ramnagar, lies the thrust fold belt of Siwalik rocks (fig. 6). These comprise the Middle and Lower Siwaliks, mainly of Pliocene age, and at places the underlying Miocene Murree formation. Composed of alternating series of resistant sandstone, clay, silt, and conglomerate, these formations represent the young Tertiary foredeep filling of the Himalayan belt. How great the crustal mobility of this area was can be guessed from the enormous thickness of this pile of rock waste, which is in excess of 20,000 feet. Locally, as along the Poonch River between Kotli and Chaomukh, normal faulting was complicated by thrust faulting, and near Ramnagar this thrust faulting was found to have been as late as early Pleistocene. The thrusting was directed from northeast to southwest and doubtless caused the convexity of the foothill belt between the Poonch and Chenab rivers. From Jammu to the confluence of the Poonch and Jhelum rivers the folds strike northwest. Beyond this confluence they meet a northeasterly structural trend, which may be called the Aravalli strike, after the Aravalli Hills, on the northwestern border of peninsular India. This northeast strike dominates the structure of the area west of the lower Jhelum and blends along this river to form what Edward Suess called the "Himalayan syntaxis." So complete is the junction of these opposed tectonic lines that they blend into a pointed triangle whose apex coincides with the sharp bend of the Jhelum River near Domel. A discussion of the origin of this important feature is wholly outside the scope of this work.[1] Suffice it to state that it led to a profound dislocation of Siwalik and earlier rocks, which naturally predisposed this region to deep erosion. This is strikingly revealed by the straight southward course of the Jhelum River between 33° and 34° north latitude.

The Pir Panjal, as the third geologic unit, is of great complexity in regard to both age and structure. In fact, it appears to be the most complexly built range in the entire sub-Himalayan belt. With rocks ranging from Cambro-Silurian to Eocene and later formations, it offers a bewildering variety of composition which has, by sheer force of mountain making, been rearranged so that four major rock units have become visible. The youngest of these is a belt of purple shales and

[1] For detailed description see Wadia, 1931.

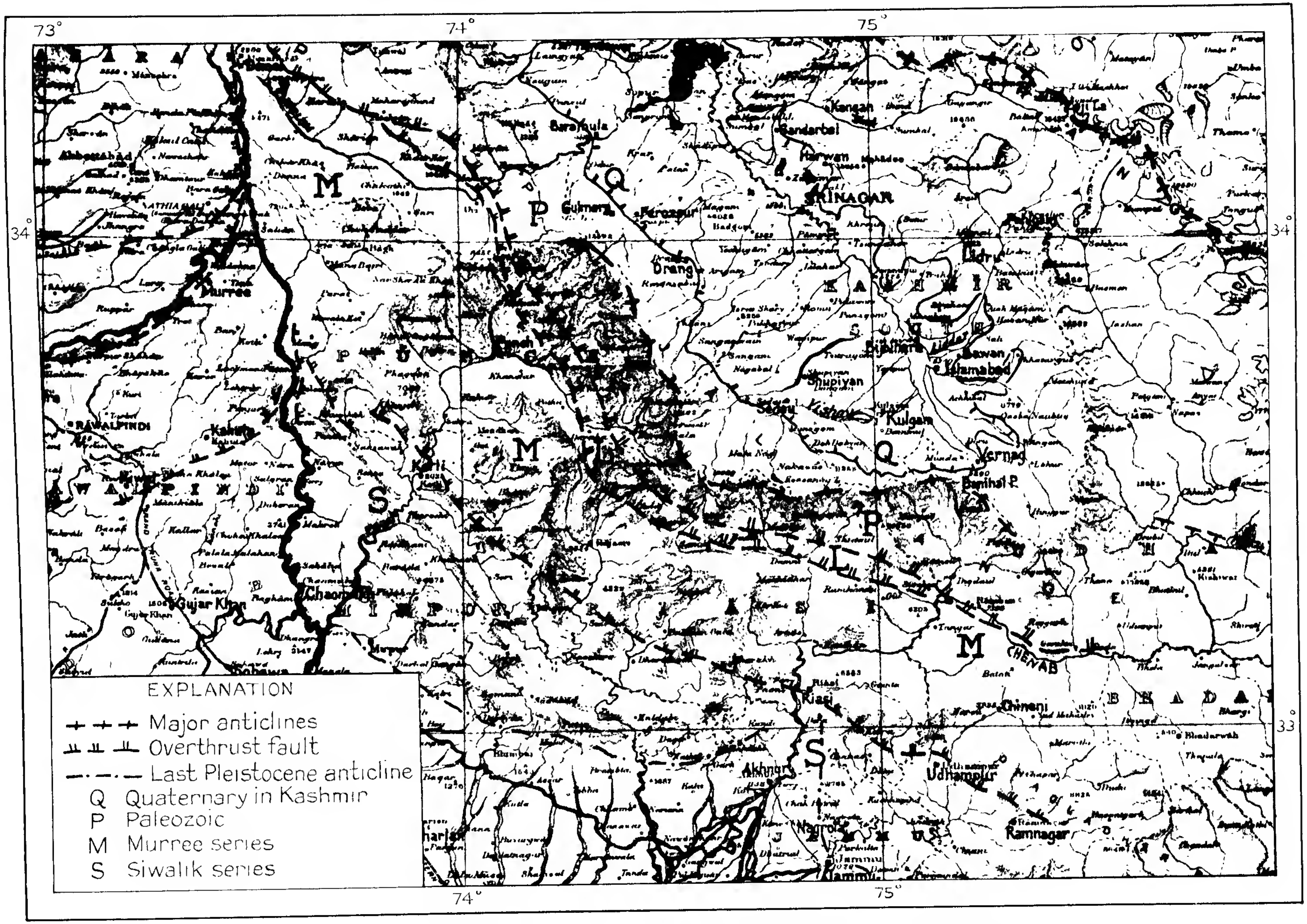


FIGURE 6. Map of southwestern Kashmir and the adjoining plains of the Punjab, with main structure lines.

sandstones of the Murree formation (Miocene mainly), representing the first sedimentary foredeep filling after the post-Eocene, probably Oligocene uplift of the Himalayas. They are friable rocks, easily eroded and liable to give rise to all kinds of folds as well as slump structure. The Murree rocks are thrust upon the Siwalik fold belt (main boundary fault in fig. 6) and are themselves overridden by a thrust mass of the higher Pir Panjal, composed of Eocene and Paleozoic formations. The southwestern thrust fault dips rather steeply northeast, but the other is flatter, thus allowing the harder overlying rocks to be removed faster by slumping over weaker Murree rocks along the thrust zone. It is in this belt that the syntaxis becomes most apparent, especially in the crowding together of two major thrust faults in the vicinity of Murree (fig. 6). The middle course of the Jhelum, between Uri and Domel, follows the southeasterly strike of a larger anticline in Murree rocks. The upper Poonch River and portions of the Chenab Valley also display structural stream control exercised by this belt.

The second Pir Panjal rock unit appears as a narrow belt of strongly compressed Eocene and Triassic limestones with thrust slices of young Paleozoic agglomerates. On account of its narrowness this zone is the least significant, although physiographically it becomes of importance in that the limestones give rise to conspicuous serrated ridges, above the softly rounded forms of the Murree shales.

The third rock unit forms the higher Pir Panjal, generally upward from 5,000 feet, and is also perceptible on the Kashmir Valley slope beneath the thick mantle of Pleistocene lake deposits. The Cambrian and Silurian slates and graywacke series, the gneiss-granites and gabbroid intrusives, mantled on the north by agglomeratic slates, make as a whole a resistant though greatly fractured and cleavaged rock complex.[1] The culminations of the relief around Tatakuti and Brama Sakul (south of Sedau) are made up of resistant dioritic and gabbroid rocks. The northwestern slope is built of Carboniferous to Triassic limestones and slates, whose outcrops appear almost in the center of the valley basin, as at Baba Hanifuddin (fig. 65). This zone probably represents a thrust mass of intricate tectonic build. Against its slope rest the Karewa lake beds, composed of clay, silt, and sand, several thousand feet thick. These beds form the fourth Pir Panjal rock unit and are the least resistant to denuding agencies. Their exposures extend from the slopes of the Banihal Pass, in the southeast, to Handawor, in the northwest, and occupy the mountain flank over a width of 12 miles, between 11,000 and 7,000 feet above sea level. (See pl. LV.)

The Kashmir Valley Basin, the fourth physiographic division, is entirely filled with Pleistocene deposits, mainly Karewa lake beds, which are strongly folded along the Pir Panjal. Here and there appear hillocks of older rocks or promontories formed by old divides, which advance from the northeastern flank and give the northern border a sinuate appearance. Structurally this valley is an intermontane fault basin with a sinking tendency relative to the general rising of the mountain belt.

[1] See map by Wadia (1934).

Above it rises the Himalayan slope with peaks 16,000 to 19,000 feet high. Cambro-Silurian rocks, Panjal trap, and Triassic to Permian limestone appear along the southeastern flank of the valley beyond the Wular Lake. They form the southern limb of a great anticlinorium into whose core extends the northwestern half of the basin. Cambrian and pre-Cambrian rocks make up the divide toward the Kishenganga River, and in the northeast the Himalayan Range exposes a thrust zone of Triassic and older granitic rocks. It is here that we find the other anticlinal crest of southern Kashmir, whose recent uplift was contemporaneous with that of the Pir Panjal.

In summarizing this geologic outline, two outstanding characteristics appear—the zonal arrangement of rock formations from southwest to northeast with progressively complicated structure, and conversely the progressiveness of uplift and folding toward the Indian plains. It is evident that this process of youthful growth of the orogenic belt must have caused profound changes in the paleogeography of Kashmir. In its present physiographic aspect this variability is strikingly exposed in the drainage pattern.

DRAINAGE PATTERN AND STRUCTURAL HISTORY

The region coincides largely with the catchment area of the Jhelum River. A tributary of the Indus, this stream belongs to that impressive line of Himalayan rivers to whose gigantic erosion this mountain range owes its awe-inspiring grandeur. Owing to the well-developed stream pattern, the Jhelum drains some 12,000 square miles. The length of its mountain course is about 250 miles to the outlet east of Kahuta. Its source lies about 12,000 feet above sea level and its outlet at the mountain border at 1,300 feet, its average fall being 43 feet to the mile. Its two largest tributaries are the Kishenganga and Poonch rivers, whose eastern side streams border the drainage area of the Chenab. The Chenab River is of second importance in the area here discussed, as its source and a large part of its middle course lie outside of this area, in the Chamba district of the Punjab province. Its average fall between Riasi, the outlet into the foothills, and Kishtwar is 34 feet to the mile.

Jhelum Tract

In view of the importance which the Jhelum tract has for the following description of the Pleistocene in Kashmir, it is necessary to analyze its course in relation to the mountain structure (fig. 6). The upper portion follows the longitudinal strike of the Kashmir Valley and is characterized by its graded condition. Between Islamabad and Baramula, a distance of about 65 miles, the average fall is not even 1 foot to the mile, and consequently the stream meanders sluggishly through the soft Pleistocene beds. This behavior clearly indicates great antiquity for the upper course and is in striking contrast to the youthfulness of its transverse middle course, where it has carved a deeply incised, in places gorgelike valley. The following discussion of the preglacial morphology shows that this portion of the Jhelum River originated on an older, less elevated land surface, presumably of late Tertiary date.

Near Baramula the Jhelum bends abruptly southwest and for 30 miles cuts across the strike of resistant Pir Panjal rocks (fig. 6). But below Uri and down to the outlet into the foothills at Owen, the course is again well adjusted to the northwesterly strike—in fact, the river flows to Domel on the axis of an anticline in Murree rocks. This fact was previously overlooked by Oestreich (1906), who extended the transverse nature down to the bend at Domel. The sharp turn of the Jhelum is not, as superficial observation might lead one to believe, a return to

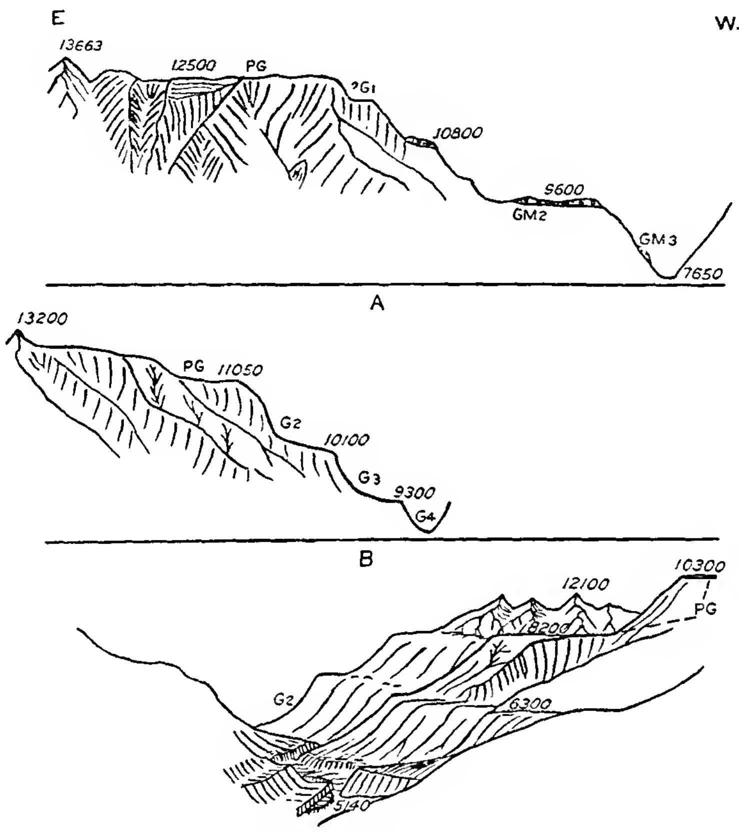


FIGURE 7.—Composite slope profiles showing relation of preglacial to glaciated valleys. A, Ferozepur Valley west of Nangni; B, Harseni Valley below Gorapathri; C, Jhelum Valley below Baramula; PG, preglacial floors; G1, G2, G3, G4, major glacial troughs; GM2, GM3, ground moraines of second and third glaciers.

the transverse course of the stream, but on the contrary a faithful expression of the structural control exercised by the tectonic syntaxis. For here the river enters the greatly dislocated zone of north-south thrust faults, whose Tertiary origin has been proved by Wadia (1931). The great depth of this valley portion is due partly to the softness of the Murree rocks, but more to the rejuvenating influence of the rising anticlinorium of the Pir Panjal. This rejuvenation becomes clearer as one analyzes the higher valley slopes, where remnants of an old valley floor indicate a state of maturity (fig. 7). This mature relief obviously is of preglacial date, as

the traces of glacial valley erosion are found over 1,000 feet below the leveled spurs and terrace remnants of the older valley. Oestreich (1906, pp. 10–11) has discussed this feature in greater detail.

So far the stream behavior is (with one exception) that of a subsequent stream directed by rock structure and intensified by uplift; but what development does it take in the foothills? From its outlet east of Kahuta to the confluence of the Poonch River the Jhelum traverses the Siwalik folds in meandering fashion, yet it retains its general southerly course (fig. 111). At first glance it seems as if this represented subsequent stream extension or inheritance into marginal lowland, the river following the course preordained by the mountain structure. The incised meanders begin on Siwalik rocks—a fact which is suggestive of a genetic relationship (pl. XXVII, 4), for the Siwaliks are, as has previously been pointed out, simply the accumulated rock waste of late Cenozoic time, and at that time they had been neither folded nor uplifted. Presumably they built a zone of loose detritus in the form of fans at the then lower and less advanced mountain border, and the rivers must have flowed across them. Indeed, the close relationship between structure and valleys of ancient origin as exemplified by the upper Jhelum suggests strongly that the rivers extended their courses into the Siwalik plains, just as the present streams extend into the Punjab lowland. On this piedmont level the graded rivers meandered and, as uplift and folding gradually increased, they incised themselves into the underlying Siwalik folds. This antecedent origin is beautifully expressed in the tributary drainage of this region, where synclinal strike valleys suddenly pursue a transverse course as they approach their master stream. Those of later origin first followed the new structures until they met or were captured by the main river. Had the Jhelum at that time been guided by another formation, superimposed on the Siwalik rocks, it would have a stream pattern different from the one which we see today. The antecedence of the lower course is in harmony with the preglacial age of the upper valley, and as this lower course developed on Pliocene detritus, the valley must have existed during this period.

On the two important tributaries, the Poonch and Kishenganga, the stream history of the Jhelum repeats itself in somewhat altered fashion. Owing to the lack of syntaxial structure, the Poonch River flows for its entire middle course in a truly transverse valley, covering the southeasterly strike of the Pir Panjal rocks. From Poonch eastward—that is, in the upper part of its eastern headwater branch—its course is adjusted to the strike in Murree rocks, suggesting a subsequent stream origin. Both streams, however, should be pictured as having developed from consequents draining the initial slope of the Pir Panjal prior to the folding of Siwalik beds (fig. 111). For the master stream surely developed at a time of lesser altitude, when the Tertiary beds easily yielded to the development of a northeastward-branching drainage pattern. Once folding and thrusting had set in, this slope drainage was turned into antecedent drainage, and the "extended consequent" course in the lowland began to incise its meanders into the younger structure. In this respect the lower course of the Poonch is similar to that of the Jhelum, for it is

at the northern foothill border, which is the Murree-Siwalik overthrust, that the Poonch River begins its meandering course.

The Kishenganga joins the Jhelum below Domel, and above the junction it faithfully follows the tectonic bend of the Paleozoic formations. Maps show that the Indus River repeats the same feature, which might suggest that the famous Indus bend around Nanga Parbat is primarily of tectonic origin.

Kashmir Valley Basin

In the Kashmir Valley the major Jhelum tributary is the Sind, which descends from the main Himalayan Range near Zoji-La. (See pl. LVI.) The upper portion of the Sind Valley between Baltal and Sonamarg follows a northwestward-striking anticline to which the stream is subsequent. At Sonamarg it turns westward, cutting across the Himalayan structure down to its confluence with the Jhelum. Presumably this stream sector is antecedent, for not only is it of preglacial origin but it has, as Paterson elucidates in a subsequent section, undergone repeated uplift on the slope of the anticlinal structure. Also there are no traces of superimposed drainage.

The northwest end of the Kashmir Valley (pl. LV) displays a half circle, from which streams descend into the basin at Handawor. This is a case of synclinal drainage at the eastern border of the syntaxis, perfectly adjusted to structure and rock composition and rather suggestive of an ancient headwater portion of a master stream. However, this question is discussed on page 29 in connection with the preglacial morphology of the region. The drainage of the Pir Panjal slope toward Kashmir shows a remarkable twofold division. From the watershed the major streams descend through deeply incised valleys, making essentially a dendritic drainage, but on the higher "karewas" this is transformed into a parallel drainage, which is the dominant scheme in the Karewa Hills. This arrangement is easily understood from a geologic angle, because the soft Pleistocene lake beds mantle the bedrock halfway up the slope, and consequent drainage developed upon them after the lake had drained off and while the range became uplifted. As a result preglacial valleys were reexcavated and several parallel slope streams developed which kept pace with the uplift, thus leading to parallel antecedent streams in the Pleistocene folds. The quick formation of a young antecedent stream pattern was favored, not only by repeated uplifts of the Pir Panjal, but also by summer rains, which fall more frequently on the northern side than on the Himalayan slope.

Another interesting feature in the stream formation of the basin is the opposite trend of some major tributaries in relation to the northwest flow of the Jhelum. Thus the middle courses of the Rimbiara, Vishav, Liddar, and Arapal rivers and the lower Sind are directed upstream with reference to the main river, and only on approaching the Jhelum do they turn sharply, as if in sudden obedience to the master stream. This can mean that the Jhelum once flowed from northwest to southeast and, if so, all these tributaries constituted a headwater drainage of a southeastward-flowing subsequent river.

Chenab-Tawi Tract

Only a small portion of the Chenab-Tawi tract falls within reach of my plan of study, and yet this is of sufficient importance to warrant a brief description.

Southeast of the Banihal Pass, which closes the Kashmir Valley toward the Chenab, the surface drops abruptly in the Chenab Gorge from 9,000 to 2,100 feet over a slope distance of about 18 miles. Thus an average fall of 383 feet to the mile is achieved, owing no doubt to the extraordinary cutting power of a stream which exceeds the Jhelum in both length and width. In southeastern Kashmir the Chenab flows alternately in longitudinal and transverse valley sections. It enters our region at Dul in a longitudinal valley whose total length of 150 miles makes it one of the major drainage lines of the southern Himalayas. This valley follows the slope of the central Himalayan range, in this respect being but a continuation of the Kashmir Valley syncline, whose tectonic nature as a recently depressed intermontane basin I have emphasized in a previous report (1935). Not only orographically and tectonically, but also morphologically, this portion of the Chenab Valley is part of the Kashmir Basin, for along it the alpine relief of the high Himalayas suffers marked depression. Southward lie the sub-Himalayas, the Chamba-Himalaya and the Dhaoladhar Range, the latter continuing into the Pir Panjal foothills north of Udhampur. Geomorphologically, then, this portion of the Chenab repeats the position of the upper Jhelum—in fact, it might be taken for the middle course of a former southeastward-flowing Jhelum River. Its northwestern tributary opposite Dul follows precisely this course, draining an area remarkable for its mature relief and relatively low altitude.

The first transverse gorge at Kishtwar is only 16 miles long and breaks through the eastern Pir Panjal as the Jhelum below Baramula cuts through this range. Curiously enough, subsequent stream adjustment to strike and Murree structure then repeats the same picture as is shown by the Jhelum, for the Chenab follows approximately, for about 50 miles, the dislocated northern border of Murree rocks. Where it once more turns southward, the river already flows at a level of 3,800 feet. The third longitudinal valley sector, which follows, is more or less conformable to the structure in Murree rocks, but north of Riasi the river changes for good into a transverse stream. It meanders freely, deeply incised, in the lower foothills as it enters the Siwalik folds. Thus the lower and upper courses repeat the arrangement of the Jhelum in regard to subsequent and antecedent origin, and even the middle course, with its threefold appearance of transverse gorges, has its parallel in the Jhelum Gorge near Baramula. In the following section it is shown that the stream patterns of both Jhelum and Chenab are derived from a preglacial relief and that the structural history has throughout guided their evolution.

Among the larger tributaries of the Chenab, the Tawi is of particular interest, as its valley contains a remarkable record of Pleistocene history. In its upper course it is an antecedent river of initial slope-drainage type. As it enters the faulted basin of Udhampur, it receives subsequent streams from both northwest and southeast which flow in strike valleys. The parallelism of stream pattern

and structure is here so perfect that south of Ramnagar three larger tributaries repeat the curvature of the strike ridges along the east end of a Siwalik syncline. These rivers are truly subsequent to structure, and even the Tawi course is deflected for a few miles within the basin. However, it then breaks successfully through the southern Siwalik ridge and enters another valley basin with subsequent drainage. Here the Tawi utilizes some old meanders and after 6 miles it cuts across the following ridge, from then on flowing in large, deeply entrenched meanders through Pleistocene detritus to its outlet into the plains at Jammu. Considering that the uplift of the southernmost front ridges is of Pleistocene age and that the Siwalik structure originated during the later Pliocene and early Pleistocene, it is by no means surprising to find the master stream antecedent and the tributaries subsequent to the structure. Had these streams been superimposed upon an underlying structure, an antecedent tributary drainage would have developed with a trellis pattern of the usual type. Evidently the subsequent tributaries are younger than the master stream, which alone was powerful enough to keep pace with the emergence of shallow folds that advanced progressively from the Pir Panjal slope to the plains.

In general, then, the drainage of southern Kashmir is well adjusted to the tectonic mobility of the region. Except for local derivations, the master streams are subsequent, with antecedent lower courses, while most of the Pir Panjal rivers are antecedent to the uplift of the range and tectonically rejuvenated consequent streams derived from an initial slope drainage. However, the glacial history of this drainage cannot be fully understood unless an attempt is made to reconstruct the morphologic aspect of Kashmir in preglacial time.

PREGLACIAL LAND FORMS

Composite Slopes and Plateau Remnants

Previous workers, especially Oestreich and Dainelli, have presented indisputable evidence for the existence of maturely dissected land forms in the northwest Himalaya. I tried (1935) to analyze the remnants of older land forms in relation to the structural history of northern Kashmir. I pointed out that the central Himalayan range exhibits a preglacial mature relief out of which developed an alpine summit level and a deeply dissected relief, molded by glaciation and rejuvenation due to uplift. The question as to which of these land forms are of preglacial age is one which cannot in general be answered offhand. The position of the mature relief relative to the glacially molded slope and valley system is naturally one of vertical superposition. Except for the younger depositional land forms, all elevated levels or remnants of broad valleys are found several hundred if not thousands of feet above the highest traces of glaciation. (See Paterson's Sind Valley sections.) This does not mean that the preglacial surface was simply one of late maturity; on the contrary, it must be stated that in all major valleys the composite slopes reveal at least one if not two phases of accelerated erosion prior to the first glaciation. In other words, Pleistocene glaciation in this region

overtook a land form which had passed through several long lasting cycles of erosion.

This is illustrated by the slope profiles given in figure 7. The Jhelum Valley below Baramula exhibits two high benches, which lie 3,200 and 4,400 feet above the stream bed and are separated from each other by a large convex slope. Beneath the lower bench is a concave slope and another bench, erosional in origin, which is followed by a deep troughlike form that carries the glaciofluvial débris of the second Himalayan ice advance. The Sind Valley shows a similar arrangement (figs. 18, 22, 23). Here the relationship of the preglacial valley stages to the glacial troughs is clearer, as shown by Paterson in his section on the Sind Valley glaciation.

This twofold division in the preglacial slope profile can only mean that the relief was in a state of rejuvenation when the glaciation began and that this had been preceded by two phases of gradation and one intermediate stage of vertical cutting. This phenomenon is widespread in the northwest Himalaya and can even

FIGURE 8.—Sketch of view from Shupiyan toward the Pir Panjal and Rimbiara Valley outlet. M, marg level; K, Karewa Hills.

be followed to the adjoining Karakoram ranges, as has previously been demonstrated (De Terra, 1935). The regional extension of these preglacial rock benches makes one suspect that they belong to remnants of mature land forms.

Plateau remnants are present along the lower Sind tract, but they are confined to narrow levels on interstream divides and nowhere exhibit a complete undissected relief. One must turn to the Pir Panjal in order to visualize what the preglacial surface was like. Figure 8 and plate XIII give an idea of the extent of the flat relief on the northern high slope of the Pir Panjal. Were it not for several parallel dissecting streams, this region would present an even, rolling upland, surmounted by peaks. It extends for 35 miles from the Rimbiara Valley northwestward to Tosh Maidan, where the plateau level slopes abruptly down to the Ferozepur Valley. The altitude is between 12,000 and 13,000 feet above sea level, or 7,000 to 8,000 feet above the level of the Kashmir Valley. The panorama picture (pl. XIII) illustrates the late mature stage of erosion and a later phase of dissection during which the initial slope drainage was rejuvenated. The relationship of the higher ridge, now the glacially molded crest of the Pir Panjal, to the surrounding plateau form is one of a "residual ridge" to the adjoining plain. Monadnocklike,

the resistant metamorphic rock mass of Tatakuti (15,500 feet) rises above the high level that cuts across Paleozoic Panjal trap and slates. Toward the northwest, this highest ridge loses in height until it almost merges with the high level at Tosh Maidan and at Gulmarg.

In the foregoing geologic sketch it was mentioned that the Pir Panjal had undergone progressive uplift. We may therefore assume that the present altitude of this area of mature relief is due to this upheaval and that its position above the Kashmir Valley is of relatively recent date. Dainelli (1922) has demonstrated that a certain relationship exists between this uplift and the folding of the Pleistocene basin filling, and the following sections give ample proof of the correctness of his views. Approximate figures for the amount of uplift are discussed and presented on subsequent pages; suffice it for the moment to assume a reduction in altitude by some 5,000 feet. The Pir Panjal must then have been a hilly range with its old relief lying some 2,800 feet above the Kashmir Basin. This calculation does not, however, include the preglacial uplift, for which the slope profiles and the disconformity between Middle and Upper Siwaliks give evidence. The altitude cited is, therefore, still in excess of the late Tertiary level at which southern Kashmir stood.

Late Tertiary Drainage and Structure

In preglacial time the watershed to the plains of India was a low ridge on which slope drainage had developed an initial relief. The Jhelum was one of the subsequent rivers in this drainage, cutting backward through Murree rocks. As uplift set in, one of its headwater tributaries accelerated its headward erosion and finally managed to approach the watershed in the vicinity of Uri. What was the condition of the Kashmir Basin at that time?

In the foregoing discussion of the present stream pattern attention was drawn to three peculiar features in the Jhelum tract—the transverse gorge at Baramula, the inversion of tributaries along the Kashmir Valley, and the synclinal origin of the valley with its possible continuation toward the upper Chenab Valley. Taking into account the stability of the northwestern watershed toward the Kishenganga, with the fully developed drainage of its convex curve and the relatively low altitude of the Pir Panjal in the extreme southeast, leads inevitably to the conclusion that the upper Jhelum during the Tertiary period must have been the headwater course of an ancestral Chenab River. This conclusion not only accounts for the peculiarities of the upper Jhelum as an old graded stream but is in full accord with the mature land forms, as deduced from other evidence. At that time the Kashmir Valley was part of this land surface, in which the drainage evidently was even more thoroughly controlled by structure than it is now (fig. 6).

The Kashmir Valley shares this ancestral longitudinal pattern with many other neighboring regions. The Indus in Ladak and the upper courses of some of its major tributaries exhibit more or less the same development (De Terra, 1934, p. 27). Evidently this structural control dates back to a time when the strike ranges were formed. This time can only have been subsequent to the last marine

phase of the Eocene sea and prior to the accumulation of the Siwalik formation, for the Siwalik doubtless resulted from erosive action by streams flowing southward. (See part II.) Under such conditions the Murree formation may already have been deposited. It is therefore probable that the principal drainage lines existed during the Miocene, although many of the transverse gorges may not yet have been fully developed.

This raises the question of the age of the Jhelum and Chenab rivers. In view of the lack of detailed information on the lithology of the Siwalik sediments, this question is almost impossible to answer. However, from the presence of highly elevated terraces in both transverse tracts, it is certain that these valleys existed long before the dawn of the glacial era. Dainelli has already contested Oestreich's view that the Jhelum Gorge below Baramula is the result of an overflow of the ancient Kashmir Lake. He pointed out that for several miles below Baramula the valley is filled with Pleistocene lake beds and that the glacial deposits near Rampur must have required the existence of a deeply incised valley of preglacial origin. This relationship of the Jhelum Gorge to the Kashmir Lake is discussed in a later chapter on the origin of the Karewa Lake.

The formation of this gorge might, therefore, be due either to capture of the longitudinal Kashmir Valley stream or to superposition of a transverse river. Superposition can be ruled out in view of the subsequent origin of the middle Jhelum course, so all that remains is to explain this 30-mile transverse tract by stream capture. If we return to the picture of an ancestral Jhelum whose headwaters eroded in Murree rocks and if we assume it to have cut farther backward into the rising axis of the Pir Panjal anticline, it becomes easily conceivable how such a tributary ultimately succeeded in cutting through the watershed, thus capturing the Kashmir Valley drainage (fig. 75B). This diversion of the Kashmir drainage through a southern stream must have greatly accelerated erosion, which led to the formation of a united Jhelum Valley and eventually to stream gradation. During this stage of early maturity a broader valley floor was formed, and after another period of stream cutting this floor remained in a fragmentary state above the incised river bed at the ancient divide.

In other words, not merely stream capture but accelerated uplift accounts for the preglacial drainage changes of southern Kashmir. Indeed, the Kashmir Valley exhibits a host of morphologic features suggestive of intense preglacial diastrophism. Apart from indirect evidence as deduced from the composite slope profiles there are places where faulting has left visible traces.

Faceted spurs, indicative of a dissected fault-line scarp, were observed on the northern slope, east of Gandarbal (pl. II, 2). Significantly enough, the triangular facets here correspond almost exactly to a fault line between Cambrian and late Paleozoic trap. Ice erosion cannot have formed these facets, for the slope east of Gandarbal was never glaciated, the Sind Glacier having had its terminus in the valley proper above Gandarbal. Southeastward, all along the lower slope of the mountains, morphologic effects of faulting can be seen. The precipitous walls of the Panjal trap northeast of Srinagar, the sudden break of many leveled spurs

descending toward the valley, the faulted condition of the Panjal trap above Zewan village, and many other fault contacts between the Triassic and Paleozoic rocks or between trap and Permian Gondwana beds signify the fault nature of this basin slope. On the corresponding side of the Pir Panjal faulting is not quite so apparent, owing to the gentle slopes of the Pleistocene lake beds and their veiling of the preglacial topography. However, in certain places, this topography has been "exhumed" by later erosion. Such is the case between Tangmarg and Petha Band, where the escarpment is 1,500 feet high (pl. LV). Between Khag and Hatbar faceted spurs appear some 2,000 feet above the Karewa lake terraces. Here the Karewa lake beds are seen resting against large triangular facets. Hanging valleys can be observed which start as broad mature valleys on the higher slope and turn abruptly into deeply cut gorges as they approach the fault line. Little confidence, however, can be placed in estimates of the amount of vertical displacement that has taken place along these border faults, for it must be remembered that both flanks of the Kashmir Valley experienced repeated uplifts during the Pleistocene epoch along pre-Pleistocene faults, so that the height of the exhumed escarpments represents the sum total of various fault movements. This matter is discussed in connection with Pleistocene structural features (p. 125).

The preglacial morphology of the area was thus determined by faulting of a narrow intermontane trough between the Himalayan slope and the sub-Himalayan Pir Panjal. The preservation of fault-line topography would indicate that the formation of strike faults was not as remote as the origin of the late mature topography, which at places is affected by the displacements. This faulting, therefore, might well have been connected with one of the preglacial uplifts to which the origin of the Jhelum transverse course is assigned. In view of the apparent convergence of the Kashmir Valley fault line toward the southeast (fig. 6), it is probable that the valley basin sank in relation to that narrow strip of country which nowadays forms the watershed between the Jhelum source and the Chenab Valley. Such a method of formation, known as transverse uplift or cross folding of longitudinal structures, is a tectonic phenomenon commonly found in the Alps and in other orogenic belts. In this area its presence is suggested not only by the termination of a fault basin on one side but by the existence of a faulted zone in the upper Chenab Valley. The crest east of the Banihal Pass probably marks a cross fold between two depressed zones whose origin doubtless dates back to the same phase of uplift and faulting to which the Kashmir Basin owes its origin and the reversal of stream flow. The ancestral Chenab River was thereby "beheaded" and subsequently diverted from its southeastern course. Whether this event was aided or initiated by capture from a southern stream must remain an unsolved problem until detailed geologic studies have been carried out in the Chenab gorges.

From the foregoing discussion it is evident that the formation of the preglacial relief antedated the beginning of the glacial era by a sufficiently long period to allow for dissection and establishment of the major drainage pattern. These events were recorded in the Siwalik series of the foothills. A variety of evidence

has already been presented (De Terra and Teilhard, 1936) to show that the massive conglomerates of the upper Dhok Pathan stage indicate the first revolution in drainage development and mountain making since Oligocene-Miocene time. Assuming that their age is late middle Pliocene and considering that the upper Pliocene was a time of great denudation, as recorded by the Dhok Pathan and the early Pleistocene Tatrot-Pinjor beds, we are inclined to date the dissection of the preglacial mature relief as late Pliocene. In such a case the older mature relief should correspond to older Pliocene and even Miocene deposits, such as the Middle and Lower Siwaliks, whose sedimentary character and perfect conformity reflect the monotonous denudation of a maturely dissected upland.

In conclusion, the preglacial period witnessed the formation of a well-dissected topography on a folded and faulted mountain belt whose southern portion was much less elevated than the northern Himalayan crest. The major stream pattern was well developed, with an outflow toward the lowland. This geographic position must have permitted the rain-bringing winds to travel farther inland than nowadays, causing greater precipitation on the main Himalayan slope than on the Pir Panjal. The impact of such paleogeographic changes on the Pleistocene history of the area here considered can hardly be appreciated unless we understand the physical geologic forces now active in this area.

PHYSICAL GEOLOGIC FACTORS NOW ACTIVE IN KASHMIR

The physical geologic factors now active in Kashmir present themselves in great variety, but because of the specific application of the knowledge gained from their study, it is necessary to select a few only. These concern present-day glaciation, fluvial and lake sedimentation, and eolian agencies.

Present Glaciation

Pir Panjal.—In the Pir Panjal there are two main clusters of glaciers. One is situated in the vicinity of Lake Konsa Nagh, near the Brama Sakul group, and the other occupies the Tatakuti group (pl. XX, 2). As both massifs lie over 14,000 feet high, it is evident that recent glaciation is restricted to the culminations of the Pir Panjal relief. In the Lake Konsa Nagh region there are about 20 glaciers on the Kashmir slope and some 6 glaciers on the Punjab slope.[1] This mode of distribution is somewhat unexpected, as the Punjab slope receives most of the monsoon precipitation. However, it should be remembered that it is the winter rains which dominantly feed the firn reservoirs of these small glaciers, and their wind currents travel from the west and northwest rather than from the south or southeast. Also the southern exposure and presumably slightly higher temperature intercept the formation of firn or glacier ice on the southeastern slope. In addition, the surface is here more dissected, and therefore the valley heads are more exposed to warm air currents rising from the plains. It seems as if the unequal glaciation of the Pir Panjal is due to climatic and physiographic factors rather than to an inherited status of glacial time, and this inference is borne out

[1] Wadia (1926, p. 13) states that there is no recent glaciation anywhere in the "lesser Himalayas."

by our survey of the Pleistocene glaciation in this region. In this respect the glaciers of the Pir Panjal do not follow the rule of Himalayan glaciation, according to which the southern or monsoon slopes carry the greatest ice cover (pl. LV). But it should be remembered that the Pir Panjal is not the main Himalaya, and its crest does not make as decisive a divide between humid and semiarid regions as the major Himalayan watershed. Accordingly, there is no slant of the snow line from north to south, as there is in the main Himalaya; on the contrary, from personal though rather seasonal observations, it seems that the snow line has a definite dip toward the Kashmir Valley. This is natural considering that the humidity is here much higher in winter than over the plains (see fig. 4) and that the winter precipitation here also exceeds that of either Murree or Jammu.

The lowest level to which valley glaciers descend in this group is 11,600 feet (according to sheet 43 K/14 of the Survey of India maps), and the average limit lies closer to 13,000 feet. (See pl. LV.) The feeding areas are in large cirques at a level of 14,000 feet, from which rise precipitous walls, covered with firn and snow. Owing to the width of these cirques, some of which measure 1 mile across, and because of the wide valley troughs below, these glacierets are pear-shaped or triangular cakes of ice, which rarely reach the typical tongue form of a valley glacier. According to A. Neve (1910) they are about 200 feet thick. The Budil Glacier only, at the head of the Harseni Nullah above Gorpathan and below the Budil Pass, is a real ice tongue. Some 1½ miles long and almost 2 furlongs wide, it occupies a deeply scoured, gorgelike depression without any névé field. The névé field is found three-quarters of a mile distant and 1,000 feet above the glacier head, occupying a large cirque north of the Budil Pass. This peculiar severance of the glacier from its feeding ground is possibly due to an ice fall which at one time initiated an unusually large advance or to a step in the valley floor.

The glacier at the southern slope of Tatakuti fills a cirque only, and its high termination at 13,800 feet indicates that it is the last remnant of a once powerful ice flow which descended through a tributary to the Poonch Valley. According to the map the Kashmir slope is devoid of recent glaciers, although Dainelli's map of the Kashmir Basin (1922) shows three small glaciers on this side which are not surveyed on the official maps. Northwestward from Tatakuti the Pir Panjal is free from glaciation, and only small patches of firn or snow fields in the highest cirques bear witness of former ice cover. The position of the snow line is difficult to fix for lack of reliable data. Permanent snow is certainly not found below 14,500 feet, and it probably does not exist except on the highest groups of peaks. The relation between snow line and glaciation in this range, therefore, remains to be determined.

In accordance with the small size of the glaciers there is very little ice erosion going on, but the moraines are, as a rule, disproportionately large. This may be due to intensive physical weathering, to nivation and frost action mainly in the cirque region. These agencies are, however, effective also on the elevated tract above 11,000 feet and cause accumulation of angular débris along slopes and in higher valleys. Structure soils, so well known from subarctic and high alpine

regions, are commonly met with wherever suitable rock material and a low angle of slant are found (pl. XVIII, 1). There is a definite relation, therefore, between remnants of the mature relief and distribution of structure and solifluxion soils, provided that these remnants are sufficiently elevated. The rock decay in high altitudes thus furnishes débris which the headwater streams must remove before they can proceed backward toward the cirque region. E. F. Neve (1912) in describing the glaciers at the foot of the Brama peaks gives the following vivid description of the débris formation in front of the ice:

> The sunshine is hot, and the silent glacier of the forenoon has become alive with sound and motion. Everywhere is the roaring sound of water. Torrents are pouring down icy slopes. Miniature avalanches occur ever and anon on the steeper faces where snow has remained, and falling stones are frequent. All the streams are swollen and laden with débris. These diurnal variations are at their height during the month of September, when the great sun heat of the day is succeeded by frost at night and the range of temperature between day and night is often 100° F.

Himalayan slope.—In contrast to the Pir Panjal, the Himalayan slope exhibits more widespread and more significant glaciation (pl. LV). There are at least 60 small glaciers, the largest of which is some 3½ miles long. The heaviest glaciation occurs around Kolahoi Peak (17,799 feet); on the crest east and northeast of Pahlgam; along the slopes of the Sind Valley, north and south of Sonamarg; and on Haramukh Peak (16,000 feet). Most spectacular of all are the glaciers around Kolahoi, which occupy the extreme terminals of the Liddar headwaters on the north slope of the peak. The Kolahoi Glacier is the longest (pl. LV), and at its mouth the Liddar River has its source at about 11,700 feet. A second powerful ice stream 3¼ miles long and about 1 mile wide lies between Kolahoi and Buttress Peak and terminates at 13,100 feet. Unfortunately no personal observations or reliable data from other sources are available to give any accurate description as to size, movements, structure, and deposition of these glaciers. From photographs and general descriptions it would seem that there are both valley and hanging glaciers with well-defined cirques and névé fields and strong terminal and lateral moraines. The morainic débris of the Kolahoi Glacier is locally piled up to 300 feet. Outwash gravel trails away from the snouts of the glaciers, but owing to abrupt steps in the valley profile, the gravel deposits are rapidly eroded and nowhere form extensive outwash aprons. In the upper Sind Valley hanging glaciers are dominant. One of them descends as low as 11,200 feet. The cirques lie between 14,000 and 15,000 feet and are, in comparison with the Pir Panjal cirques, well filled by ice. From their snouts extend thick boulder moraines, very coarse, and in many places covered by perpetual névé beds. The concentration of glaciers north and south of Sonamarg is not accidental, for it is here that the moisture-laden winds are forced to precipitate after they have traveled unchecked through the transverse tract of the Sind Valley. This situation is reflected in the meteorologic records (see fig. 4), which indicate heavy precipitation in late winter and early summer. Similarly the heavy glaciation around Kolahoi coincides with a catchment area for rain-bringing winds, which travel from the Banihal Pass

across the valley and up the Liddar to precipitate on the buttress of Kolahoi. In the upper Taigwas and Nilagrar valleys, with their short but wide hanging glaciers, lie the remnants of the formerly rich ice reservoirs of the ancient Sind Glacier. The longest ice tongue at Haramukh lies north of the peak and occupies the topmost terminal of the headwater of the Wangat River, a main tributary of the Sind. It is a little over 2 miles long and ends at about 12,100 feet above a large lake that occupies an abandoned cirque. E. F. Neve (1912, p. 88) mentioned that on the south side glaciers terminate at 13,500 feet.

All these glaciers carry heavy loads of rock débris, for the summit and cirque region is precipitous and nivation very active. In addition traprock is brittle and so are Paleozoic slates and Triassic shales, which readily furnish large quantities of débris for the moraines. In this connection it is noteworthy that the abundant Triassic limy shales and slaty limestones in the headwater region of the Sind and Liddar valleys provide a large supply of calcareous rock flour, which is being transported into lakes and rivers of the Kashmir Basin.

Although the average cirque level is at about 14,500 feet and the average lower limit of glaciation at 13,000 feet, the snow line keeps to about 15,000 feet. As the relative position of all these levels is largely controlled by altitude, precipitation, and exposure, and as these factors must have changed greatly in a mobile region such as Kashmir, it is evident that this scant information is rather insufficient for reconstructing previous relationships of snow line and glaciation.[1] It would also appear that paleogeographic changes, as outlined above, must have shifted the proportionate share of any of these factors so that the empirical knowledge gained from recent glaciation cannot readily be applied to previous glaciations. One fundamental fact, however, stands out—the close relationship between glaciation, altitude, and exposure to monsoon winds. The Pir Panjal, bearing the brunt of monsoon precipitation, is not sufficiently high and is too greatly exposed to bear extensive valley glaciation, whereas the Himalayan slope, in spite of lesser precipitation, carries on its higher surface a glaciation three times that of the sub-Himalayan range.

River Action

Most rivers in this area are in a state of erosion, and over large tracts, such as in the Jhelum Valley between Baramula and Owen, in the Chenab Valley, and along large portions of the Poonch and Sind valleys, no heavy deposition is taking place. But wherever these streams are graded they drop their load and thus cause heavy deposition of sediment. One of these regions is the upper border of the plains in Jammu and Poonch, where rivers continue to accumulate both gravel-sand and silt sediments. The composition of these fans is varied, but on the whole it is coarse, with boulder gravel and coarse sand being swept incessantly through the winding stream channels. To the primary supply of débris from the foothills and the Pir Panjal is to be added the sand and silt supply from the Siwalik formation, through which the rivers must pass on their journey to the plains. Above

[1] See Dainelli, 1922.

all, it is the vast store of loose gravel in the Boulder conglomerate ridges of the outer foothills that furnishes streams and rivulets with great quantities of coarse débris.

The impressive width of these fans and the rate at which sand banks and mud flats shift indicate a rapidly working geologic process. So far, no studies of foothill sedimentation have been undertaken in northern India, although the problem is of sufficient magnitude and data could easily be gathered. The newly constructed irrigation canals in Jammu and in the Punjab provide reliable sources for a study of this kind. As the water in these canals is deeper and its flow regulated, the figures gained would be somewhat in excess of the true rate of deposition in stream channels. This is particularly evident in an accumulation of gravel which I observed along the Chenab-Jhelum Canal between Akhnur and Jammu. This canal was constructed along the slope of a ridge composed of Upper Siwalik conglomerate, and as numerous rivulets drain the dip slope to the plains at right angles to the irrigation channel, each rivulet required a tunnel to allow outflow beneath the canal bed. In these rivulets, whose course had been somewhat regulated by an embankment made of cobblestones, 5 feet of gravel had accumulated since the irrigation canal had been constructed, 10 years ago. The tunnels beneath the canal bed had almost filled up with boulders.

Along the Jhelum, in the Kashmir Valley, deposition of silt and clay is also rapid, but under flood conditions this river carries most of its silt load in suspension. In spite of this, the river does not deposit its load to such a degree that its bed is gradually elevated. On the contrary, it manages to erode laterally and to carry the new sediment downstream. This is possible only because of the lack of sedimentary supply from its headwater region and because of the swift flow in flood condition, which enables the Jhelum to concentrate on widening its channel and on moving the resultant load downstream.

Lake Sedimentation

The lake sedimentation in Kashmir is of special interest, for lake deposits of glacial age cover almost the entire floor and southwestern flank of the Kashmir Valley. Thus the knowledge gained from hydrobiologic studies can be applied when it comes to interpreting the sedimentary record of the Pleistocene lake beds. It is fortunate that the biologic survey of Professor G. E. Hutchinson in Kashmir, which was carried out on my second expedition in 1932, resulted among other things in a careful study of bottom samples, which Lundquist (1936) investigated. According to this study the types of sediments of the Kashmir Valley lakes are of gray color, free from calcium carbonate, and entirely of the shallow-water type, as the lakes are now in a stage of filling through plant growth and silting up. The deepest lake is Manasbal, with a maximum depth of 12.8 meters. Mineral grains generally measure 10 μ and make up 20 to 30 percent of the sediment. Fragments of fresh-water shells are numerous, and in the Lokut Dal the top layer is richer in them than the bottom layers. This varying distribution of shell fragments is probably dependent on their solubility, due to varying degrees of

carbonate and humus content in the lake water. The dominant component is fine detritus containing slime of algae and especially diatoms, of which 229 species have been listed. In hydrobiologic terms they represent diatomaceous fine detritus gythja. The following table gives, according to Lundquist, some essential data on the lakes investigated:

Lake	Depth in meters	Percent by volume			
		Coarse detritus	Fine detritus	Mineral grains	Diatoms
Lokut Dal	1.2	54	33	2	1
Bod Dal	4	54	68	29	3
Sundar Khun	5	23	56	10	5
Manasbal	12	23	75	18	7
Wular	5	23	70	28	2

From this analysis it appears that the bottom samples from Lakes Wular and Bod Dal have the highest percentage of mineral grains, which is natural, because they receive fresh sedimentary supply from two rivers, one of which is the Jhelum, which flows through Lake Wular. Also the diatom content is relatively low in these two lakes.

The rate of sedimentation is difficult to determine on account of the variability of supply. We can, however, assume that it is greatest in Lakes Wular, Bod Dal, and Ankar, which receive the greatest supply from streams. However, this supply evidently was checked and counterbalanced in past ages by erosion through lake currents, for otherwise the lakes would have been silted up more rapidly. This must be particularly true for Lake Wular, through which the Jhelum flows before it enters the transverse valley at Baramula. Present-day lake sedimentation, therefore, is different from what it must have been in a large sheet of water such as existed during the Ice Age. It is this consideration, and also the lack of observations on annual deposition, which make further discussion of this geologic process unnecessary.

Eolian Agencies

The mere fact that Kashmir lies in the storm path of monsoon currents makes one suspect the existence of strong eolian activities. Anybody who visits the Punjab plains and Kashmir during the spring and early fall witnesses severe dust storms. Normally these storms arise semiannually, before the southeast monsoon and before the winter rains. Figure 4 shows that during these months rainfall is scarce and the humidity of the air low. Moreover, the alluvial soils, naturally rich in silt and clay, are then exposed to intense solar radiation, which leads to evaporation of capillary water, thus preparing the topsoil for the flight. Severe storms begin in April and last until the end of May, when the first rains begin. At this time the air is so heavily laden with dust that from a hill station like Murree the sun occasionally appears like a yellow disk behind a veil of dust. The quantity of silt thus suspended must amount to millions of tons. As the dust veil thins

out over the Kashmir Valley tract, it is evident that the greatest precipitation must take place in the plains and along the foothills of the Pir Panjal. But in the Kashmir Valley local air currents, such as diurnal winds along minor valleys, whirl up topsoil from alluvial fans and terraces, especially from the Pleistocene lake beds, which furnish an inexhaustible supply of loose silt and clay. These dust storms travel far north into the mountains, and a host of observations is available from travel literature to show that pink silt is carried as far as the large Karakoram glaciers and to the edge of the Tibetan plateau. This phenomenon existed during the Ice Age also, as is revealed by a recent study of pollen-bearing interglacial lake beds from Lake Panggong, in Ladak.[1] Pine and other pollens were reported from this place, which in interglacial time was as dry and unforested as it is now. Thus the pollen can only have come from Kashmir, where, as will subsequently be shown, coniferous forests clad the slopes of the Pir Panjal. In recent time wind-blown pollen is deposited at the bottom of many Kashmir lakes, as Wodehouse's investigation (1935) revealed. Wind, therefore, was and still is an agency with which the geologist must reckon in this region.

In this area precipitation is the medium through which the suspended dust again falls on the earth. Especially the first summer rains and to a lesser degree the first winter rains precipitate this dust veil and deposit thin films of silt. Naturally the annual amount thus deposited is small, but given sufficient length of time this eolian deposition must furnish demonstrable quantities of new soil. Perhaps it is this which gave the Kashmiris the admirable idea of cultivating roof gardens, whose gay colors delight the traveler in hamlets and cities. A direct proof for eolian deposition in historic and prehistoric times is to be found in the deep burial of ruined sites, as at Burzahom, where a megalithic culture of neolithic age is buried under more than 12 feet of loessic soil (pl. XXIV, 2). A conservative estimate for the age of this site is 7,000 years, which would, at the minimum, mean an amount of 20.5 inches of silt per thousand years. Historic sites such as the temples of Avantipur and Martand had to be excavated from loam layers 6 to 8 feet thick. In such places, however, rain wash from surrounding hill slopes has partly caused the deep burial.

Thus glacial, fluvial, lacustrine, and eolian agencies sculpture as well as add to the relief of present-day Kashmir. Equipped with this knowledge of geologic structure, land form, climate, and vegetation, let us now proceed to interpret the records of the Ice Age.

B. THE GLACIATION ON THE HIMALAYAN SLOPE

By T. T. Paterson

GLACIAL SEQUENCE IN THE SIND VALLEY

The Sind River (see pl. LVI) is the main tributary of the Jhelum in its mountain tract and drains a large area of the southern flanks of that part of the inner Himalaya which bounds the northeast side of the Kashmir Valley. Its source

[1] See Deevey, 1937.

is in a rock basin close by the foot of Saskat, a peak in the Ogput Range, which runs parallel to the main Himalayan range, from northwest to southeast. From Saskat [1] the Sind drops steeply northeastward to reach the main strike valley, where it

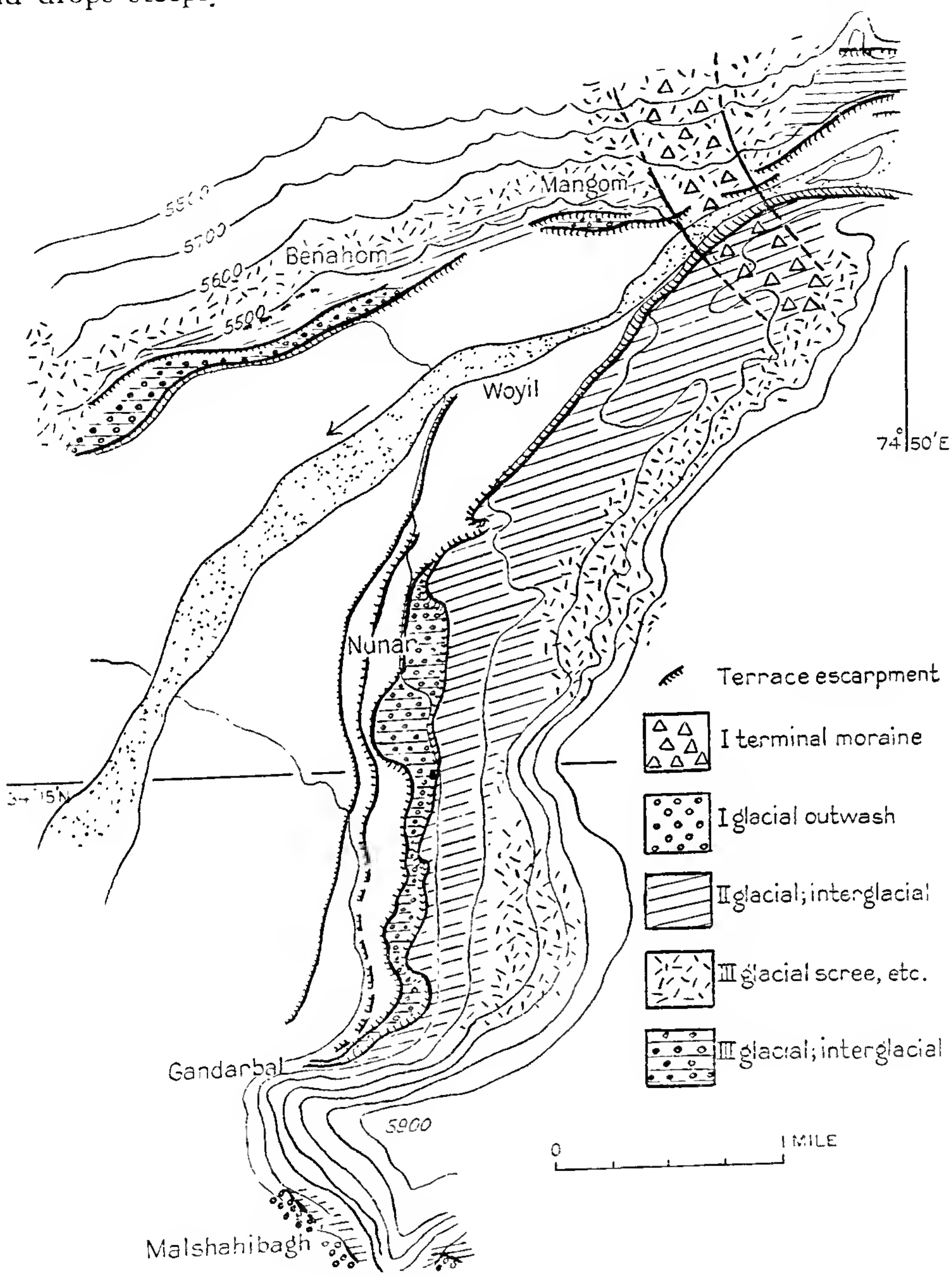


FIGURE 9.—Map of lower Sind Valley.

flows northwest, receiving on the way the cold waters of the Kolahoi Glacier, which is the largest in the Sind drainage system and which reaches its snout at 12,100 feet. Gathering momentum, the river runs toward Sonamarg between

[1] Places referred to in the text and not given on figures 9, 15, 24, 28, 37, and 41 will be found on the ¼-inch map 43 N./SW., and the 1-inch maps 43 J/15 and 16 and 43 N/3, 4, and 7 of the Indian Survey.

steeply towering mountain walls, over a boulder-strewn bed, constantly threatened by tremendous fans from the north banks, emerging into the pleasant upland serenity of the Sonamarg, as if to rest before it plunges in a roaring headlong torrent sharply to the southwest through the Gagangiyer Gorge, 4,000 feet deep. This gorge cuts the Ogput Range and brings the Sind into a well-wooded vale gently curving to the southwest, where it discharges over a wide delta into the Kashmir Basin. This delta, over 4 miles in width at Gandarbal, narrows rapidly upstream, so that 4 miles up, at Woyil, the river can be crossed by a single small bridge (pl. III, 1).

By the Sind lies the ancient caravan route to Ladak, branching off at Baltal to cross the pass of Zoji-La. So it was that the early Himalayan geologists here made some traverses. Drew (1875) observed glacial striae 450 feet above the valley floor at Hari, at Suprhar,[1] and again at Gund. Lydekker (1878, p. 46; 1879, p. 34) also saw striated rocks at Kulan, 5 miles above Gund. Oestreich (1906) noted that glaciofluvial deposits were common below Gund and attributed the basin above Gund to the action of a glacier tongue. Drew had already recognized the trap content of the moraines of Sonamarg, lying within a limestone basin, and thought the moraines indicative of a retreat stage of the Sind Glacier. Oestreich believed that these moraines were piled up against the narrow Gagangiyer Gorge.

Dainelli (1922) made more intensive observations on the glacial sequence. He recognized four main glaciations as follows:

(*a*) *First glacial.*—The Sind Glacier advanced as far as Ahateng Hill and Manasbal Lake, the evidence being in glacial molding of the Ahateng slopes and the adjoining lower hill. There is also, according to Dainelli, glacial molding of the hill slope behind Malshahibagh (fig. 9). Marinelli (see Dainelli, 1922) maintains that the lateral spurs on the right bank of the Sind near the outlet are faceted.

(*b*) *First interglacial.*—The cemented conglomerate of Malshahibagh rests on the glacially molded hill slope and underlies the Karewa clays laid down as the Karewa Lake began to form.

(*c*) *Second glacial.*—The ice advanced. How far is not stated, but the fluvioglacial deposits and glacial trough below Gund are given in evidence.

(*d*) *Second interglacial.*—Dainelli makes no mention of this stage except to point out that probably the Upper Karewa clays were laid down in the lower Sind.

(*e*) *Third glacial.*—The ice advanced and reached Gund, as shown by the striae, roches moutonnées, glacially scooped floor, and moraine.

(*f*) *Third interglacial.*—This is not discussed.

(*g*) *Fourth glacial.*—The ice again advanced in the upper Sind as far as Sonamarg, producing moraines there. Dainelli notes two terraces at Sonamarg which he correlates with the fourth glaciation, and a later, termed the Bühl, parallel to the Alpine sequence. He also saw the possibility of ice oscillations as shown by additional moraines below Baltal (pl. LVI).

The Sind Valley, Dainelli points out, has been cut into a mature topography which shows signs of rejuvenation of erosion prior to the glacial cycle, but the depth of the valley, he maintains, is due principally to glacial erosion.

[1] Probably Sura Pharao; see fig. 28.

Dainelli's evidence for the lowest limit of glaciation was closely examined, and it seemed to the writer that the molding of the Ahateng and Malshahibagh slopes is not due to glacial action.[1] Further objections were raised:

(*a*) Ahateng is protected by the spur at Repor, which would have deflected the glacier southward. The Repor spur is not glaciated.

(*b*) To mold the slopes of Malshahibagh the glacier would have had to round the Gandarbal ridge, and would then have been gouging in a direction at right angles to the main valley stream.

(*c*) To mold the slopes of Ahateng and, at the same time, those of Malshahibagh would have required a glacier front in that region over 1,000 feet thick and 7 miles wide. There is no evidence of such an extensive advance.

Later, Norin (1925, p. 165) made notes on the Sind Valley glaciations. He observed above Mangom the remains of a terminal moraine three-quarters of a mile wide and 200 feet high, and noted that the erratics had come from places as far away as Sonamarg. Inside the moraine he saw a thick deposit of gravel and sand, which he traced as far as Margund, and he interpreted this deposit as "glacigenous proximal sediments genetically of esker character." These pass into yellow clay which he found exposed at Gund and beyond, in contact with ice-worn rocks. At Rezan he noted the presence of a terminal moraine enveloped in conglomerates and then the Sonamarg moraines at Shitkari. At Sonamarg he remarked the cemented conglomerate seen by Dainelli and traced it to Baltal.

The following account is intended to give a further interpretation of the Sind glaciations. The terraces and moraines indicated in figure 9 were mapped by plane table on a scale of 2 inches to the mile. As the heights of the terraces varied in different parts of the river, owing to differences in erosion and position on the thalweg, it has been found more convenient to use numbers rather than heights to designate terraces. This facilitates comparison with other river systems. The terrace surfaces are numbered therefore T1, T2, etc. The symbol TD refers to the surface of deposition of the second interglacial material and is higher than T1, which was eroded out of it during the late second interglacial period. It should be pointed out that the terrace surfaces, especially the higher and older, are not generally uniform, but differ in height considerably, owing to late erosion and to varying proximity to the main channel of erosion which produced the succeeding terrace. A scale for heights is given with each of the sections.

The whole valley may be divided into three parts depending on a varied physiography due principally to localized tectonic movements and to regions of glacial advance. Thus the lower Sind is a mature pre-Pleistocene form (pl. III, 2), extending from the outlet to a point near Hari and carrying the evidence of the oldest glaciations only. The glaciated profiles produced by the first two advances are now well worn. Here too occurs the region of deposition, with large and thick deposits of outwash and of lake clays. The middle Sind extends from Hari to the natural boundary formed by Gagangiyer Gorge. In this part the third glacial advance alone has produced moraines, and the evidence for the earlier glaciations

[1] Dr. deTerra and Dr. Teilhard de Chardin subsequently investigated the region and agreed with this conclusion.

lies well above the present valley floor in old profiles, truncated by erosion into a rising block hinging at Hari. (See discussion of figs. 29 and 30.) The upper Sind carries the moraines of the fourth and later ice advances above Gagangiyer Gorge and can be divided into the Sonamarg Basin and the Baltal Valley. It has been found convenient to describe each of these parts consecutively.

Lower Sind

Mangom moraine.—The Mangom moraine (pl. IV, 1), first recognized by Norin, is the lowest and earliest undoubted morainic deposit, and, owing to its clear relations to other glacial and interglacial strata, it was used as a key to their interpretation. It lies at a height of 5,500 feet, and on the left bank, almost 200 feet of its height is exposed where it is enveloped in coarse fluvioglacial deposits. On the right bank the moraine has been cut away and partly covered by fine débris, but large erratics mark its former extension, producing a distinct ridge in the fan. In plan the moraine is definitely arcuate, being wider and reaching lower down on the right bank, probably owing to the swing of the valley at this point.

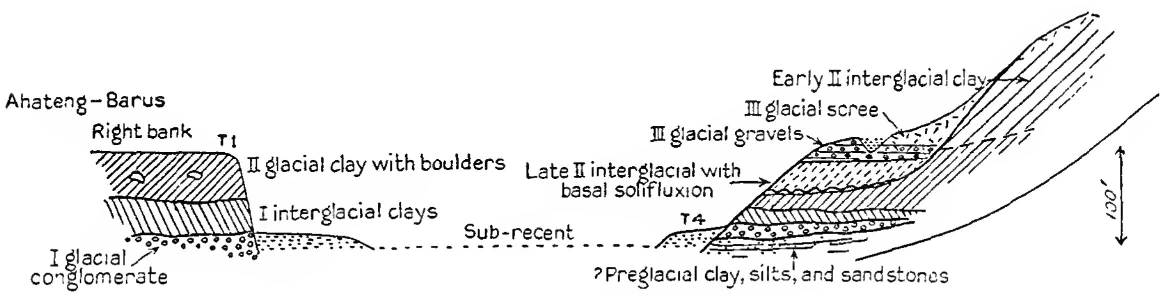


FIGURE 10.—Composite transverse section, Gandarbal to Ahateng.

It is steeper on its inner edge, sloping more gradually on the outer edge, and is composed of angular and subangular blocks of local and foreign material as large as 35 by 20 feet, down to screelike small angular chips in a yellow clay matrix. Many of the blocks are derived from the trap of Gagangiyer, and limestone from the Triassic beyond that region is common. The form and structure are those of a terminal moraine.

First glacial.—The next Pleistocene deposit is the conglomerate that immediately overlies the Mangom moraine (fig. 10). Its lowest occurrence is at Malshahibagh, and it extends up as far as Hari, where it lies on a glaciated floor 500 feet above the present stream bed (fig. 29). At Malshahibagh (fig. 9) it is characterized by small, coarsely rounded pebbles not more than 4 inches in diameter, composed principally of gray Triassic limestone, quartzite, slaty rocks, and grits cemented by hard calcareous matter. Here it lies with an irregular contact upon crumbly, coarse, and gritty sandstone, with subangular grains, which in turn rests upon a greenish sand with clays possibly of preglacial age. The surface of the cemented conglomerate forms a smooth pavement and is banked at an angle of 7° to 15° upward toward the hillside. Lenses of coarse gritty sandstone similar to that underlying the conglomerate are interbedded with the conglomerate.

There is much hornblende and augite. In places the conglomerate is overlain by sandy, gravelly beds, locally with a yellow-brown interstitial clay. The whole thickness at this point is not more than 30 feet. One mile northeast of Gandarbal it can be seen as a very coarse conglomerate, with the surface pavement removed by solution, underlying a very thick deposit of yellow clay in the bed of an irrigation channel (fig. 11). Upstream toward Nunar this conglomerate again crops

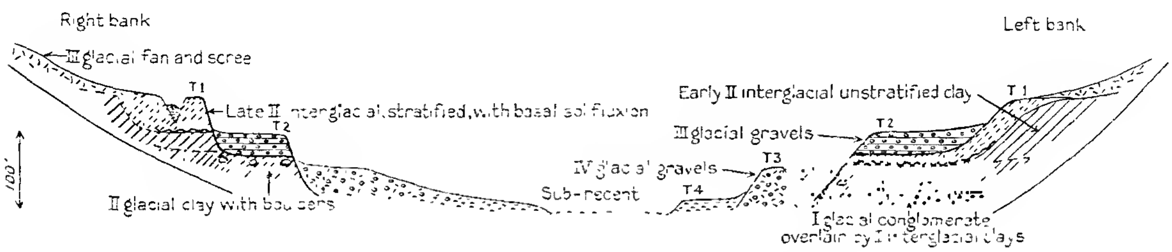


FIGURE 11.—Composite transverse section below Nunar.

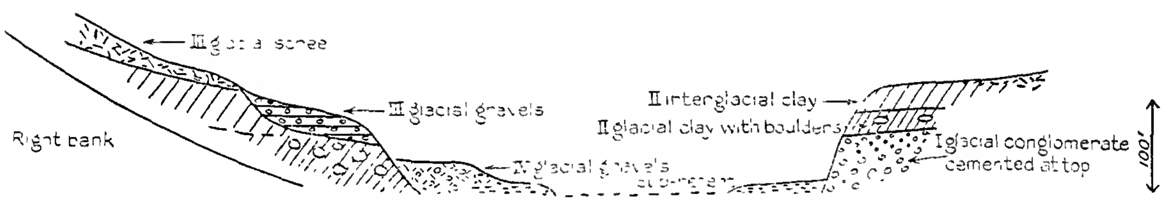


FIGURE 12.—Transverse section at Woyil, below the Mangom moraine.

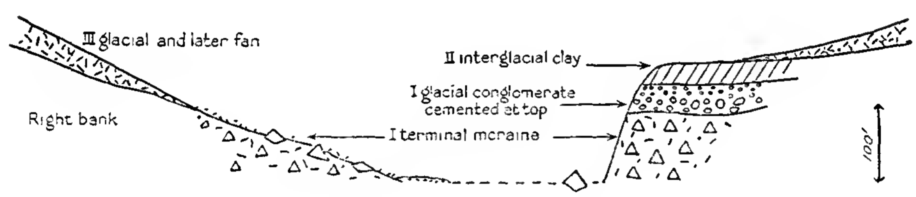


FIGURE 13.—Section across the Mangom moraine.

out, showing boulders of heterogeneous size, the largest 1 foot in diameter. From Nunar upward the conglomerate thickens rapidly to 100 feet at Woyil, where there is a marked change in facies (fig. 12). Here there is great heterogeneity in size and material. Much interstitial sand with subangular boulders and clayey matter of gray-brown appearance can be seen—weathered biotite, gneiss, granite, purple trap, quartzite, and grits. There is a strong brown staining toward the top, probably due to contact with the clays above, which can be seen to overlap the conglomerate at the 15th milestone. The conglomerate passes over the moraine and close to it contains boulders several feet in diameter in a reddish-yellow sandy matrix (fig. 13). Toward the top it is much finer and is cemented and gray.

The conglomerate has filled up the hollow on the inner surface of the moraine and shows, on the left bank, some patches of sand; but, traced farther upward to

Dragtiyung (figs. 14, 15), it belongs completely to the boulder facies, and the upper layers are strongly cemented, with the Triassic limestone and gray calcareous matter as at Malshahibagh (fig. 16). Forty feet of the loose heavy boulder

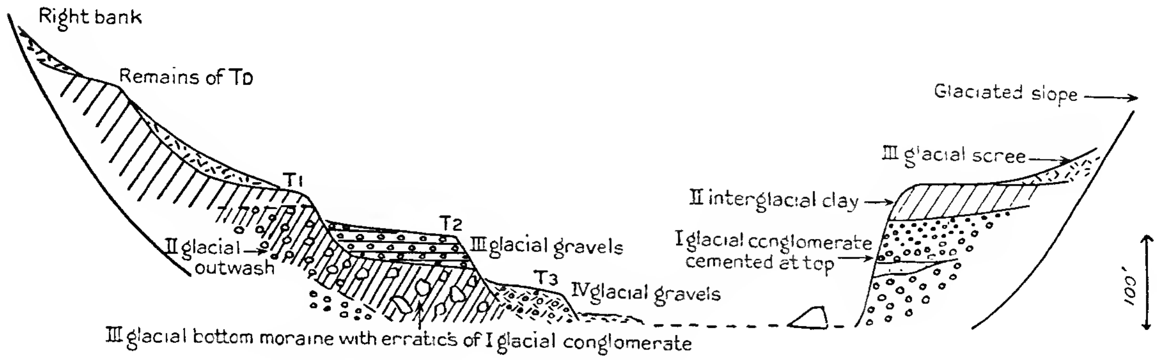


FIGURE 14.—Transverse section above the Mangom moraine.

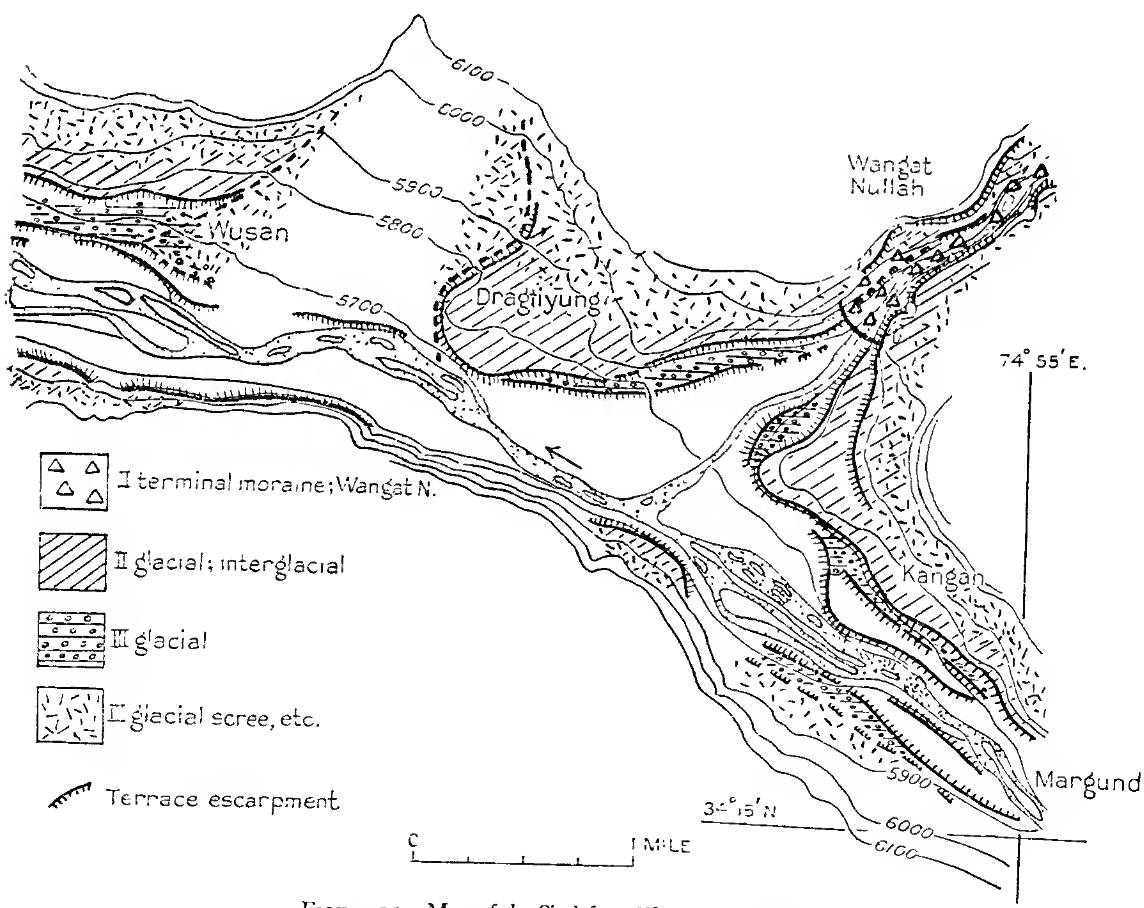


FIGURE 15.—Map of the Sind from Wusan to Margund.

material containing much Triassic limestone in a yellow sandy matrix can be seen half a mile below the 26th milepost below Mamar (fig. 27, C) and can be traced thence to Mamar, where the boulders are as much as 3 feet in diameter. The

variation in character of this conglomerate from Malshahibagh to Mamar (fig. 17) is probably due to outwash during a retreat phase of the ice; that is, when ice on retreat was at Kangan, then coarse material would be deposited at Woyil and a finer equivalent at Gandarbal; when the ice was at Sura Pharao, then the coarse material would be at Mamar and the finer on top of the coarse at Woyil. A belt

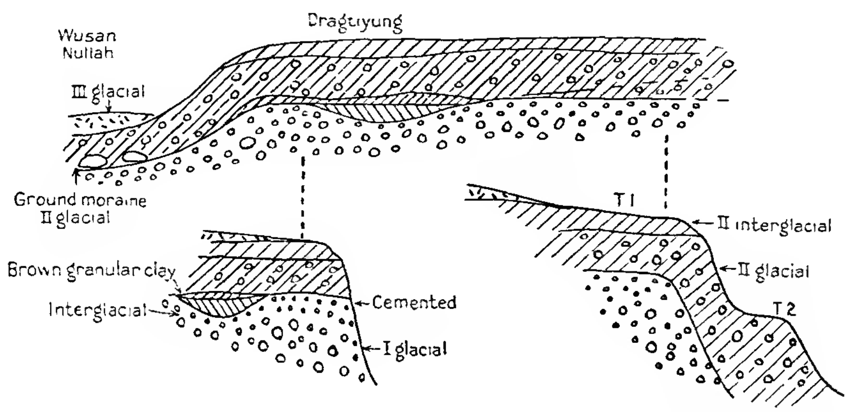


FIGURE 16.—Transverse and longitudinal sections on the right bank of the Sind at Dragtiyung.

of large erratic boulders in the stream bed near Mamar may represent a halt in the retreat of the second glacier, for they seem to be derived from the second conglomerate, which is there more heterogeneous than the first.

On the right bank opposite Gandarbal, at Barus, below Ahateng, the first glacial material is a fine cemented conglomerate with sandy bands, like that of Malshahibagh (fig. 10).

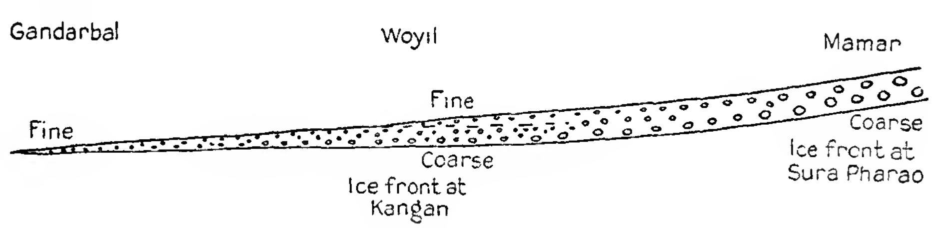


FIGURE 17.—Variation of facies in first glacial conglomerate.

At Woyil the heterogeneity of size of the constituent members of the first conglomerate, especially the large blocks close to the moraine, the variation in provenance, the frequently subangular character and faceting, and the lack of any bedding even on a large scale suggest glacial origin, and the close relation of the deposit to the Mangom moraine, with the true fanlike deposition (thinner and finer outward), indicates outwash on the retreat of the glacier that produced the moraine.

First interglacial.—The first interglacial period, succeeding the deposition of the "cemented conglomerate," saw the inundation of the Kashmir Basin by a lake with quiet and fairly deep waters in which were deposited a series of finely laminated yellow clays and silts, succeeded by earthy yellow clays with no banding, perhaps laid down during a later period of shallow water. Naturally they are

thickest in the basin itself and are best seen immediately east of Malshahibagh, where the Srinagar road winds its way on to the main terrace. Similarly they can be seen overlying a hard yellow laminated silt with concretionary bands at Barus (fig. 10). They overlap the first glacial conglomerate at Nunar (figs. 11 and 19), where the laminated clays are absent, but these clays appear again at Dragtiyung (fig. 16), where there are well-banded yellow clays with thin laminae, sandy toward the top, easily cut by a knife, and very like hardened varves. Below Kangan (fig. 18), again the earthy yellow clay overlies a well-laminated clay with fine

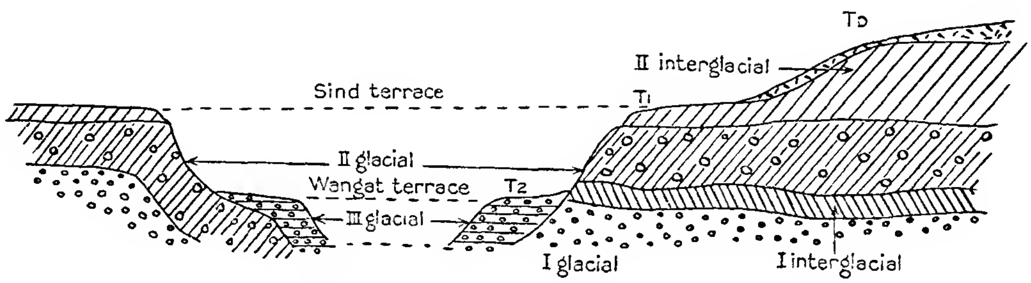


FIGURE 18.—Transverse section across mouth of Wangat Nullah.

sandy bands. The bed itself is tilted valleyward at 10°, perhaps owing to the superincumbent weight of the second glacier, which has eroded the surface of the earthy yellow clay. Thallophytic plant remains are the only fossil contents.

These yellow stratified clays and silts are termed the Lower Karewa clays.

The Lower Karewa lake must have decreased in depth sufficiently for an erosion to take place prior to the deposition of the second glacial conglomerate, for, between Dragtiyung, Wangat Nullah, and Kangan the second glacial material

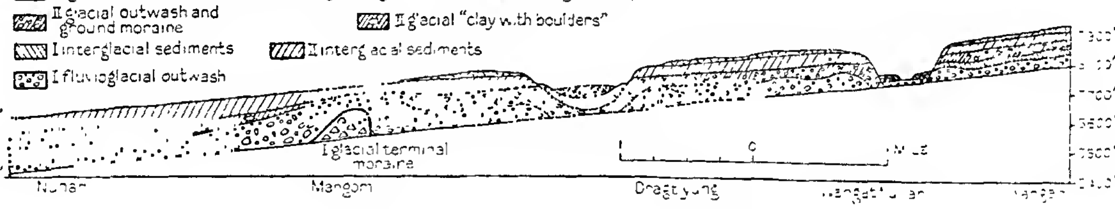


FIGURE 19.—Longitudinal section, Nunar to Kangan.

was deposited against a buried terrace escarpment cut into the conglomerate (fig. 19). This same erosion removed the first glacial conglomerate on the inner side of the Mangom moraine on the right bank so that the second glacial conglomerate is banked directly against the moraine at that point (fig. 14).

Second glacial.—The second glaciation produced no terminal moraines of the size and low altitude of the first, even though it was as extensive, if not more so. There are two forms of glacial deposits belonging to this stage.

1. Below Woyil (fig. 11), the earlier deposits are overlain by a yellow-brown clay carrying large faceted subangular and angular boulders as much as 15 feet

in length (pl. IV, 2). The boulders are of gray, green, and white quartzites, fine grits, purple olivine trap (from the vicinity of Gund), a gray traprock with amygdaloidal calcite, reddish-brown fine-grained bedded and coarse sandstones, and gray micaceous schists. This yellow-brown clay with boulders is well exposed on both sides of the valley between Gandarbal and Nunar (figs. 10 and 11). The faceted pebbles and boulders have been used for building walls around the gardens of the village of Benahom. Sometimes sharp, angular fragments are found scattered in lenses in this clay, and pockets of boulders are similarly disposed. The clay is entirely without stratification; therefore there can be seen no contortion of bedding under the large boulders. There is some slight banding well down the valley, but this is entirely unaffected by the presence of the boulders. This deposit is seen to overlap the first interglacial clays below Woyil (fig. 9) and is generally separated from these clays by a red-brown granular clay which is inconstant in character.

2. Above the Mangom moraine, in the hollow excavated by the first interglacial erosion (fig. 14), very large boulders appear again in a yellow-brown matrix of clayey texture. The boulders are subangular and faceted, not angular like most of the boulders of the Mangom moraine. There are large numbers of small rounded pebbles, and no water assortment can be seen. Boulders of the first glacial cemented conglomerate are covered by and pass upward into a great thickness of very coarse conglomerate, which is distinct from the first glacial conglomerate in that it is entirely noncemented, contains little or no Triassic limestone, and has a brown-reddish matrix more sandy than that of the earlier conglomerate below. The boulders are on the whole larger and subangular, faceted, and very much ironstained. This conglomerate is finer in the top layers and is well exposed at Dragtiyung, where it overlies the first glacial and interglacial deposits, separated from it by red-brown granular clay (fig. 19). It can be traced as far up as Mamar (fig. 27).

The second variation above Mangom closely resembles some of the Scottish boulder clays, and, on account of its matrix, lack of assortment, form, and faceted boulders, it is interpreted as a ground moraine, the overlying conglomerate being the fluvioglacial outwash of the same glacier. The material farther down the river seems to have been formed differently, and the following conditions are postulated: The Lower Karewa lake lost depth (already the first interglacial deposits had been eroded), and a brownish granular clay began to be deposited. It would appear from the lack of stratification and even banding that this clay was laid down rapidly, and, as it is in texture and lithology like the clay associated with the immediately succeeding glacial deposit, up into which it passes conformably, it was probably produced during the active glacial erosion, which was then increasing in the highlands. The decreasing depth of the lake perhaps may not be dissociated from the onset of glaciation and a retention of a great part of the precipitation as ice. Then the depth began to increase rapidly immediately before the maximum extension of the Sind Glacier, a phenomenon probably due to damming of the Jhelum outlet by uplift of the Pir Panjal and deposition of moraines in the valley of the Jhelum River.

The water was now deep enough to float the glacier when it reached a position near Mangom. A fjordlike appearance can be envisaged (fig. 20). Into the long valley of the Sind the water extended, submerging the first moraine and its fluvioglacial outwash. The second glacier, overriding the first moraine, floated, and from its face broke off small "icebergs," which carried into the lake large erratics, dropping them into the rapidly deposited glacial clay. According to Dainelli (1922) these icebergs carried boulders even across the lake and down the Jhelum Valley, where they can be seen as erratics at Rampur and Uri. (For discussion of this hypothesis see p. 180.) Very probably the fact that first glacial

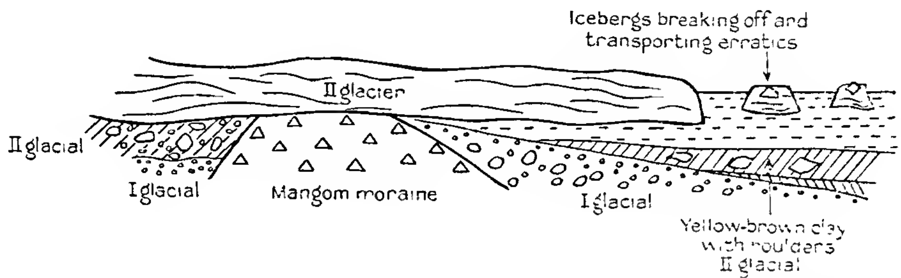


FIGURE 20.—Postulated conditions at Mangom during time of greatest extension of second glacier.

clays still remain above Mangom is due to the buoyancy of the ice in the water, resulting in a decreased erosive power. As will be seen from the remarks below on Wangat Nullah, the second glacier of that valley reached its outlet into the Sind and there deposited a large terminal moraine, so that the Kashmir Lake of second glacial time was not deep enough to extend so far up the valleys as to be able to float a glacier at the level of Kangan. If we assume, because of the thickness of the terminal moraine, that the Wangat second glacier was of the order of 200 feet in thickness, then the lake level of second glacial time might not have been higher than 6,100 feet. Therefore, as the Sind Glacier began to float at a point near Mangom, the ice there could not have had a maximum limit of thickness of more than 500 feet.

No true moraines of a period later than the second glaciation occur below Hari (fig. 24). Therefore the strong U profiles to be seen at Wusan, Kangan, Margund, Mamar, and Hari (pl. III, 1; figs. 25, 26, and 27) must be due to the first and second ice advances. Therefore the valley must have been eroded approximately to this level in pre-Pleistocene time. (See also preglacial sediments at Malshahibagh, fig. 10.) Moreover, as will be seen (figs. 29 and 30), since the upper reaches were higher during the first glaciation, then the first glacier had a steeper gradient than the second; therefore, since the latter reached as far as Mangom and on less gradient, it can be argued that the first glaciation was not so powerful as the second. Moreover, from the course of striae and depth of oversteepening the ice must have been nearly 300 feet thick at Hari and Mamar and less at Mangom, for it has been pointed out that the Wangat Glacier formed its own terminal moraine. Hence the second ice at Mangom cannot have been more than 250 to 300 feet in thickness.

Second interglacial.—The second interglacial period seems to have been a long one, for much of the early sediment was removed by later erosion and many of the boulders of the second glacial conglomerate are much weathered in comparison with similar rocks of third glacial and later age.

The early second interglacial sediments succeed the conglomerate conformably and consist of red-brown and yellow-brown clays, wholly unstratified except toward the top, where banding occurs. This clay and the preceding second glacial deposits are grouped under the name Upper Karewa series. The Upper Karewa lake must have been deep and extensive, for relics of this clay are to be found at heights of 400 and 500 feet above the valley floor near the outlet of the river, above Gandarbal, where the lake level must have been about 6,000 feet. (For discussion of the possible effects of uplift on the height of shore lines, see p. 98.) The great part of this early second interglacial deposit was removed by long-continued erosion during a subsequent period of the second interglacial phase, producing a terrace, T1.

In the upper reaches of the river the surface of T1 is entirely an erosion surface cut into the old deposition surface TD, which is to be seen only in isolated patches, principally at the mouth of Wangat Nullah and above Kangan (figs. 15 and 23). The greater part of these upper terrace surfaces are obscured and even obliterated by vast quantities of scree produced during the succeeding cold third glacial period. Lower down beyond Mangom, as base level was approached, deposition increased so that the T1 in these lower parts (as for example at Wata Lar, below Mangom on the right bank) was constructed of redeposited "kankar-bearing" (concretion-

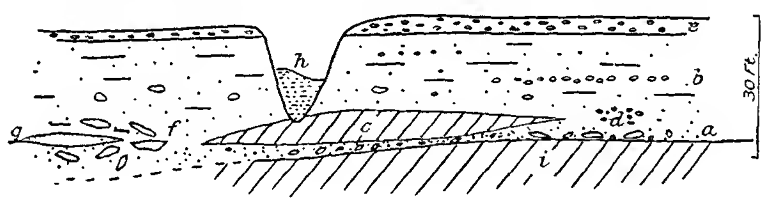


FIGURE 21.—Section immediately west of Benahom. *a*, Up-ended boulders, rounded and subangular, solifluxion; *b*, sandy stratified yellow clay; *c*, reddish granular clay in a large lens; *d*, pocket of pebbles; *e*, top bed, well stratified, local pebbles; *f*, facies *b* with scattered boulders; *g*, lens of rough pebbly sand; *h*, gully with infilling of hill wash in yellow clay matrix; *i*, second interglacial unstratified yellow clay without pebbles or boulders.

ary) clay with lenses of gravel, and up-ended boulders at the base (pl. V, 1). These boulders were derived partly from the second glacial conglomerate, because some retain signs of faceting. West of Benahom a good section is exposed along the side of an irrigation channel (fig. 21), showing this late second interglacial material overlying the Upper Karewa clays. Similar material is exposed between Nunar and Gandarbal, cut into the early sediments and overlain by third glacial material. These relations are indicated in figure 11.

At Gandarbal, still lower down (fig. 10), this erosion-deposition phase is represented by 4 to 5 feet of yellow sandy clay with beds of rounded pebbles overlying

1 to 3 feet of local subangular boulders as much as 2 feet in diameter in a red iron-stained matrix. The arrangement, up-ended and nonbedded, suggests a solifluxion deposit, like that at Benahom. The same disturbance of the lower beds can be seen in the extreme deposit half a mile southeast of Malshahibagh, where there is exposed 20 feet of sandy yellow clay with layers of pebbles and boulders as large as 1 foot in size.

The presence of a basal solifluxion deposit indicates, at least, an increase in precipitation producing soaking of the ground and hence soil flow. Concurrently with an increase in precipitation an advance of the glacier front would be expected,

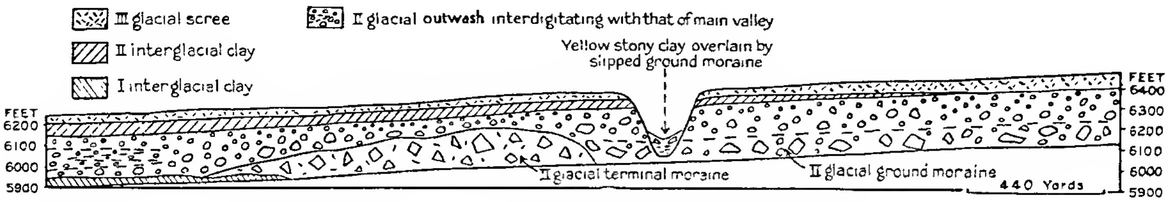


FIGURE 22.—Longitudinal section at mouth of Wangat Nullah.

but, as this solifluxion was not nearly so intense as that which accompanied the third glaciation (described below), then the advance, it can be argued, was not so extensive as that of the third glacier. Hence the indications of a second interglacial oscillation of the ice front must lie somewhere above Gund, and, as the second glacial and the greater part of the second interglacial deposits lie at a high level above the present valley floor and are therefore very much eroded, such indications may have been almost entirely obliterated. The writer saw none, but it is possible

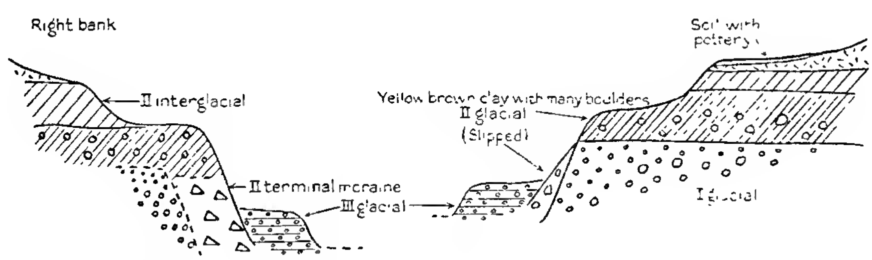


FIGURE 23.—Transverse sections across the lower part of Wangat Nullah.

that a large fan breccia of second interglacial age in the Sonamarg Basin can be ascribed to this period. (See figs. 38 and 39.) The erosion of T1 may be connected with this increase of precipitation, but there is also evidence to show uplift in the Ogput Range at this period. (See discussion of figs. 29 and 30.)

Wangat Nullah.—The Wangat Nullah enters the Sind Valley just below Kangan (fig. 15). About a mile up from the mouth can be seen the relics of a large terminal moraine over three-quarters of a mile wide near the village of Shodawan at 6,100 feet. Large angular boulders as much as 40 feet in diameter litter the valley floor, and in the sides of the terraces (fig. 23, section at left) others lie in a yellow-brown clay matrix interspersed with angular fragments of a variety

of rocks, many not of local origin. This moraine lies in a valley cut out of first glacial cemented conglomerate which appears below the village of Baimlun on the left bank (fig. 23, section at right). In the stream bed where the outer limit of the second terminal moraine is exposed the ice can be seen to have picked up masses of red-brown clay with black bands, a clay which appears in place, puckered and disturbed, immediately underneath the moraine. From its position this clay seems also to lie in the gully cut into the first conglomerate, and as it is older than the second glacial advance it can be assumed to belong to the initial period of the development of the Upper Karewa lake, immediately prior to the second glaciation and after the first interglacial phase of erosion as shown above Mangom and at Dragtiyung.

The second glacial conglomerate is very thick and envelops the moraine completely, at the same time covering the ground moraine which lies above the terminal (fig. 22). This conglomerate has much clay in it and interdigitates with the conglomerate of the same age in the Sind Valley, the difference being only in the greater abundance of Panjal trap in the latter. It is overlain by an early second interglacial yellow-brown clay which is continuous with that in the main valley, and this in turn is covered by scree of third glacial age. On both sides of the valley appear small escarpments marking the deposition surface of the early second interglacial clay about 250 feet above the valley floor. There is a strongly marked late second interglacial erosion surface at about 150 feet, then a lower terrace of third glacial age at 40 to 50 feet.

Of still later age are gullies cutting these terraces and filled with yellow clay and scree. At Baimlun village near the moraine, the surface of the second interglacial clay has been covered with a loess-loam partly podsolized, which seems to be associated with the third glacial terrace. On this is a thin covering, 4 to 5 feet thick, of gravel of local origin. On top of this is a soil of wind-blown loam carrying pottery of a kind associated with the megalithic sites of the main valley and like that found with polished stone tools in the wind-blown and water-laid clay of gullies in terrace T3 at Nunar. On the surface occurs modern pottery.

Farther upstream the terraces T1 and T2 become indistinct and disappear at Wangat, 7 miles up. The bed of the nullah is littered with large boulders, and scattered patches of conglomerate stick to the steep hill slopes as far as the place where the valley becomes narrow and steep. Here the conglomerate, too, disappears, leaving only the large erratics of ground moraine and truncated spurs as evidence of the extension of the ice. Still farther up, Gangabal Lake is reached at 11,600 feet, lying in a moraine-dammed cirque. The moraine is fairly fresh in its topography and may belong to the fourth glaciation.

Lower Sind above Margund.—Above Margund (fig. 24) the valley shows more cogent signs of former glaciation. From Kangan to Mamar the profiles are distinctly oversteepened, and a well-marked truncated spur on the right bank near Tserawan is clearly seen from Margund (fig. 26). At higher altitudes well-defined "nicks" in the valley profiles are quite consistent (fig. 27), and seem to be of preglacial age.

Figure 27 shows three sections on the right bank between Margund and Mamar, at the points marked A, B, and C on figure 24. The second glacial conglomerate and early second interglacial clay can be traced almost continuously from Kangan to Margund. In these higher parts the surface of the second inter-

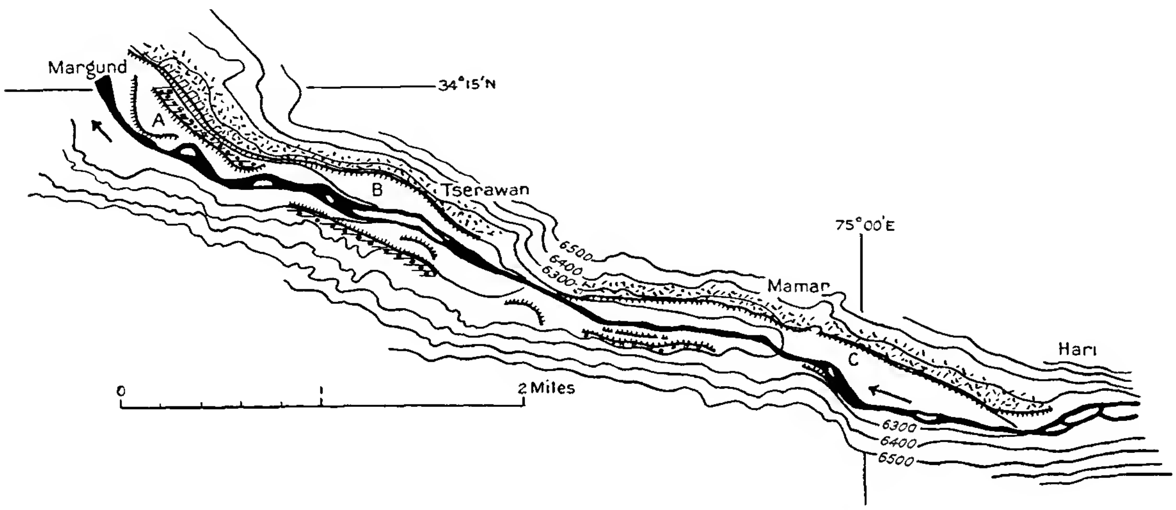


FIGURE 24.—Map of the Sind from Margund to Hari. Symbols as in figures 9 and 15. A, B, C, localities of sections shown in figure 27.

FIGURE 25.—View upstream from Kangan, showing spurs on the left bank.

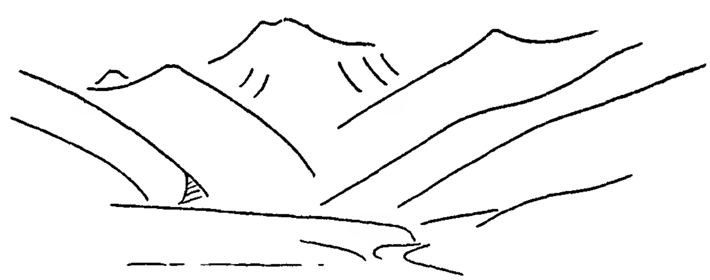


FIGURE 26.—View up the Sind 2 miles beyond Margund, showing oversteepening on the left.

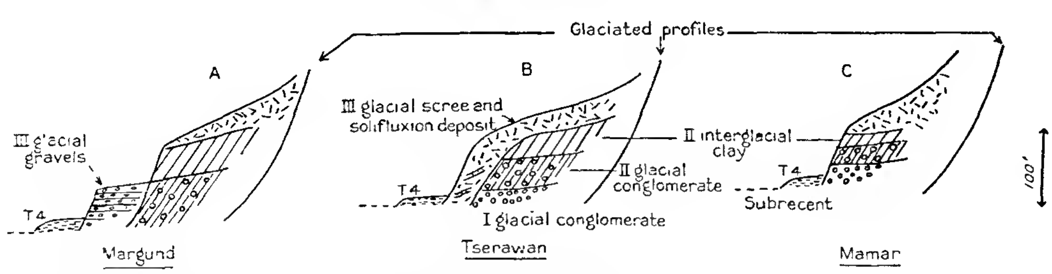


FIGURE 27.—Transverse sections on right bank of the Sind between Margund and Mamar, at points marked A, B, C, figure 24.

glacial clay, presumably cut by the second interglacial erosion, is completely hidden under a capping of angular scree débris, progressively thicker beyond Margund. At Tserawan (B) this capping overlaps completely the eroded second glacial and interglacial deposits, its structure being well exposed in the cutting of the road as it winds round the terrace below B. Here it is composed (pl. V, 2),

as Norin (1925, p. 169) describes it, "of angular flat fragments of shale held together by a clayey matrix. Amongst the gravel are interspersed numerous large boulders. The sediments are distinctly assorted by water, and intercalations of stratified clay occur at several horizons. Part of the angular gravel and the large boulders evidently issued from the steep tributary valleys." The stratified clays thus mentioned are loesslike in character and dip riverward at about 5°. A close examination of the exposure of over 100 yards at the site of the photograph (pl. V, 2) failed to yield anything but local material in this deposit, and the water assortment is of a very rough nature, the stones being disposed at all angles. The boulders were compared with those, also of local origin and similar rock, brought down in the big fan issuing from a side valley on the right bank at Mamar. The boulders in this comparatively modern deposit, derived from no great distance, are much more rounded and worn than those in the Tserawan terrace section. Norin has classed this Tserawan material with the conglomerate of Kangan and Dragtiyung—that is, as being of second glacial age—and regards it, as mentioned before, as "glacigenous proximal sediments genetically of esker character." But it has been seen to overlie second interglacial clays and envelop the late second interglacial erosion surface. Therefore it must be of later date. Moreover, as Norin has noted, at Gund it interdigitates (fig. 35) with third glacial material. The lack of foreign matter, the preservation of angular character in contrast even to late fan material at Mamar, and the paucity of water assortment except toward the middle of the valley suggest its origin as a local solifluxion deposit derived from the immediate hill slopes. Such formations have been observed by the writer in Greenland and Baffin Land slipping downhill by solifluxion during the spring thaws, and produced initially by the intense frost shattering under extreme cold. The interdigitation of this material with third glacial deposits and its erosion during third interglacial time suggest its age as third glacial.

Here in the upper parts, below the third glacial moraines, it is thickest (fig. 27, C), because the valley is narrower and steeper-sided than below, where the deposit is represented by shelving slopes of scree débris covered by similar more modern formations at the inner borders. The water assortment toward the middle of the valley, as well shown at Tserawan, can be seen only where a deep section is exposed, as the outflow from the third glacier snout was running in a channel there. Hence the terrace of the third glaciation is not found immediately below the third moraines except as an erosion channel, but it appears below (figs. 10, 11, 12, 14, 18), where the river reached toward base level, as a terrace aggradation, showing gravels principally of local material and with a large quantity of little-worn pebbles derived from the washing of the local solifluxion deposit. The fine brown clay which is so commonly interstitial in these third glacial gravels is similar to the loesslike bands mentioned as occurring at Tserawan. At the base of these gravels, as seen at the village of Dedmaribagh, between Nunar and Gandarbal (fig. 11), there appears a pebble conglomerate which in places carries with it boulders as much as 2 feet in diameter, perhaps derived from earlier material. Much of this pebble gravel is disarranged like that which occurs at the base of the late second inter-

3233.

glacial aggradation gravels of this same region, and may also be a solifluxion deposit.

These gravels generally form T2 and may be cut into early or late second interglacial beds (figs. 10, 11, 14, 18, 19), and, along with the solifluxion material, can be traced up to the third moraines (fig. 28). The erosion surface against which they are laid is more marked in the upper portions, just below the moraines (fig. 27), and, except for the strongly marked fan deposit immediately fronting the moraines, where a coarse outwash facies alone is apparent (fig. 29, below Sumbal), aggradation is confined principally to the lower parts of the lower Sind.

Before entering upon a description of the middle Sind it would seem best at this point to remark upon the terraces of the lower Sind. The ages of TD, T1, and T2 have been demonstrated. There are two lower surfaces, T3 and T4 (fig. 11). The third glacial gravels have been strongly eroded, and against them are banked rather loose gravels of variegated character. The vast majority are derived from preceding deposits, as witnessed by the size, shape, and color, and the interstitial material, of which there is little, is sandy, with some clay. As indicated below, T3 and T4 can be traced to the upper Sind. T3 is there associated with the fourth glacial advance, and T4 with later stages. At Sonamarg the fourth glacier has deposited its terminal moraine in an erosion channel of third interglacial age (see explanation of figs. 39 and 40), over 100 feet in depth. It must surely be represented in the lower Sind, and such an erosion channel can only be the well-defined scarp cut into T2. It is also evidently greater than the channel cut by the third glacial advance (fig. 11), and, as the third glaciation was much more intense than the fourth, it can be assumed that the above-mentioned scarp cannot have been formed wholly during the fourth glacial stage. It would be expected that there would have been some deposition during the third interglacial stage in the lower Sind, but certain indications of such deposition have not been seen. A gravelly silt exposed in T3 at Shahpur, a mile north-northeast of Gandarbal, may be of third interglacial age, but there is no section visible to indicate its relation to the gravels of T3, which are, in the figures, marked as belonging to the fourth glaciation. As already indicated, these gravels are associated in the upper Sind with outwash of fourth glacial age, and their turbulent arrangement in the middle and lower Sind suggests their formation under torrential conditions, but in the lower Sind the possibility still holds that they mask an earlier deposit laid down under the quieter conditions of the third interglacial period. A thin layer of loam caps this terrace, and much of it has been redistributed along irrigation channels.

Terrace 4 in the lower and middle Sind is inconstant in appearance, owing to its low level and its removal by the swing of the river in its modern bed. The gravels are like those being reassorted by the river today, derived by erosion of previous terrace gravels and conglomerates. Any interstitial material is silty sand and usually of dusty gray color. In the middle Sind this terrace is more strongly marked than in the lower. In the upper Sind it corresponds to terraces 3 and 4 of Sonamarg, which are there related to the fifth and sixth glacial advances. Belonging also to this period are deposits of hill wash, fairly fine gravel,

and clay with angular chips of local rock, which have been laid down in gullies that cut T3 (fig. 11). These gullies are confluent and seem to be associated with old irrigation channels now filled in with wind-blown and water-laid clay, mostly derived from the covering loam of T3. From the clay in one place at a depth of 20 feet has been recovered pottery of megalithic age, as at the village of Baimlun, in the Wangat Nullah.

Between Dragtiyung and Wusan (fig. 15) the fan from Wusan Nullah is cut into, partly by T3 and wholly by T4, except for the modern portion and closely adjoining borders. The fan is therefore principally of third glacial age, and in support of this conclusion it was noticed that at Wusan it was difficult to differentiate between the fan gravels and the third glacial gravels of T2. The fan was of greater extent before third glacial time, as shown by the burial of the old fan limit at Dragtiyung under second glacial material (fig. 16). There is a fan issuing from a side valley opposite Kangan (fig. 15), and here too the lower fans are cut into the greater part of it. The great development of fans in the third glacial period and their persistence since that time is also well shown in the upper Sind.

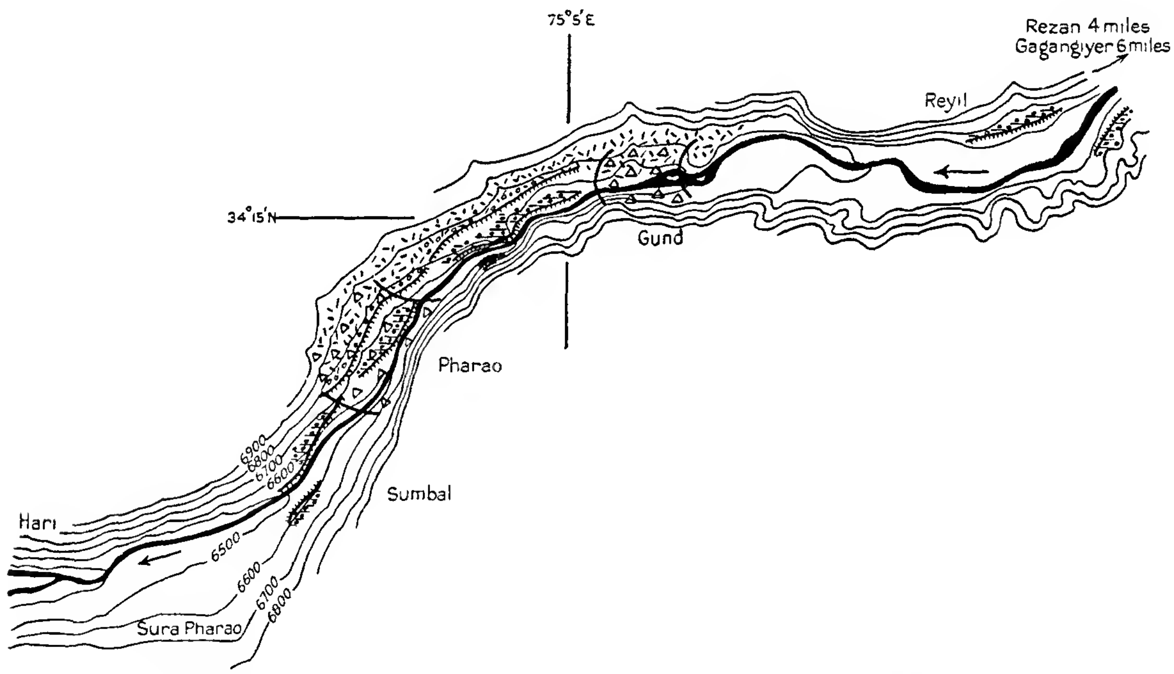


FIGURE 28.—Map of the Sind Valley from Margund to Reyil. Symbols as in figures 9 and 15.

MIDDLE SIND

The middle Sind extends from Hari (fig. 28) to Gagangiyer Gorge. It is characterized by a distinct increase in the thalweg slope, the presence of four terminal-moraine belts of third glacial age, and the suspension of truncated profiles of preceding glacial phases above the present valley floor. This last-named feature becomes evident from Hari onward.

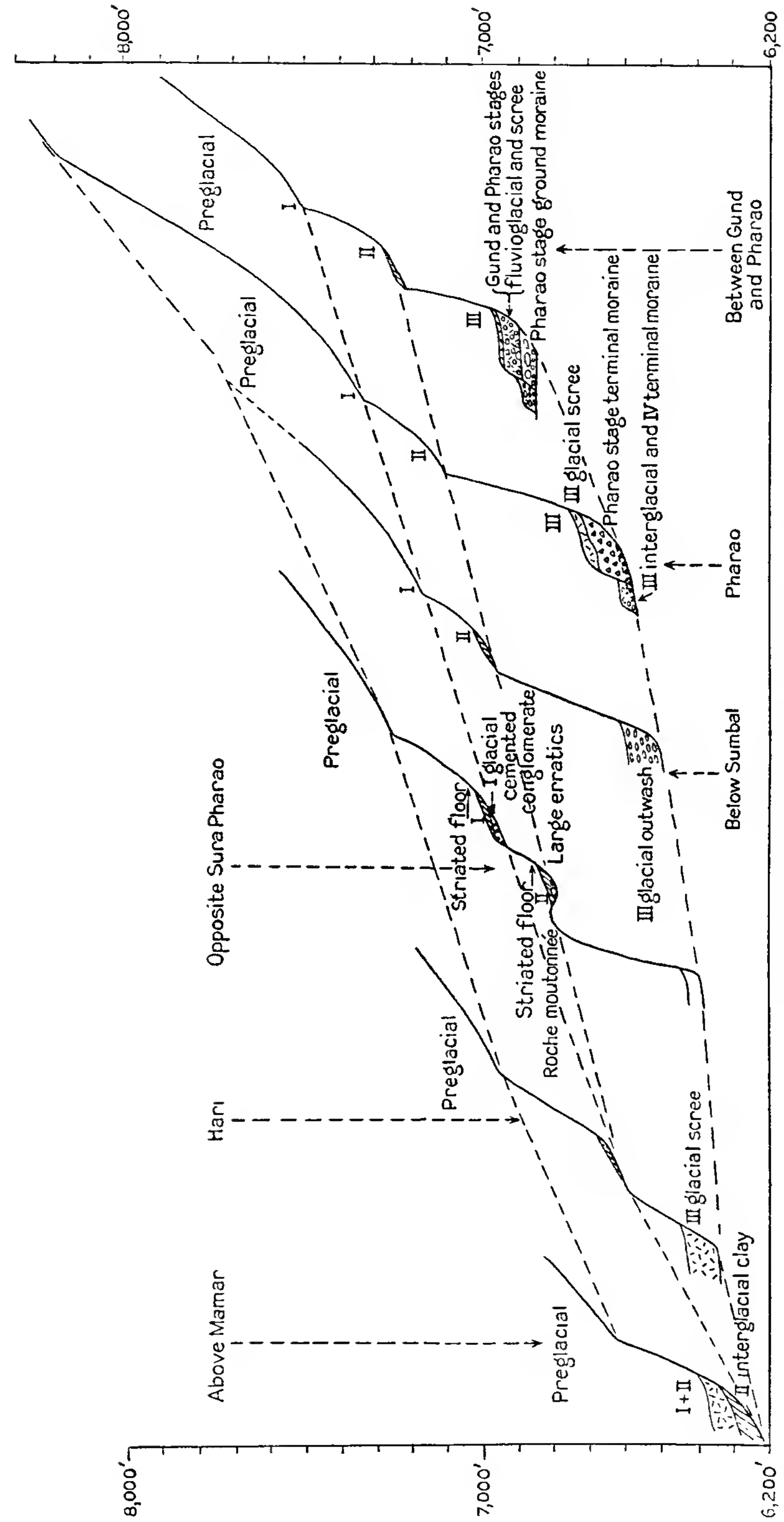


FIGURE 29.—Valley profiles between Mamar and Gund.

Figure 29 illustrates six valley profiles on the right bank between Mamar and Gund. Above Mamar itself the first glacial and second glacial and interglacial deposits lie against a glaciated profile steepened by the first and second ice advances (cf. fig. 27, C). At Hari this U-shaped form lies over 250 feet above the present floor, and in its hollow rests some yellow-brown clay with angular fragments of local rock, which may be a late denudation product.[1] The U form is truncated by a steep 250-foot cliff which has suffered no oversteepening—the third ice did not reach this level—and is obviously a fluviatile erosion form. As typical third glacial scree is banked against it, and also third glacial outwash a little way up, it must be of second interglacial age. Opposite Sura Pharao the higher level U form is composite. There is an upper one over 200 feet in depth, 500 feet above the river. Here typical first glacial cemented conglomerate rests against a glacially striated

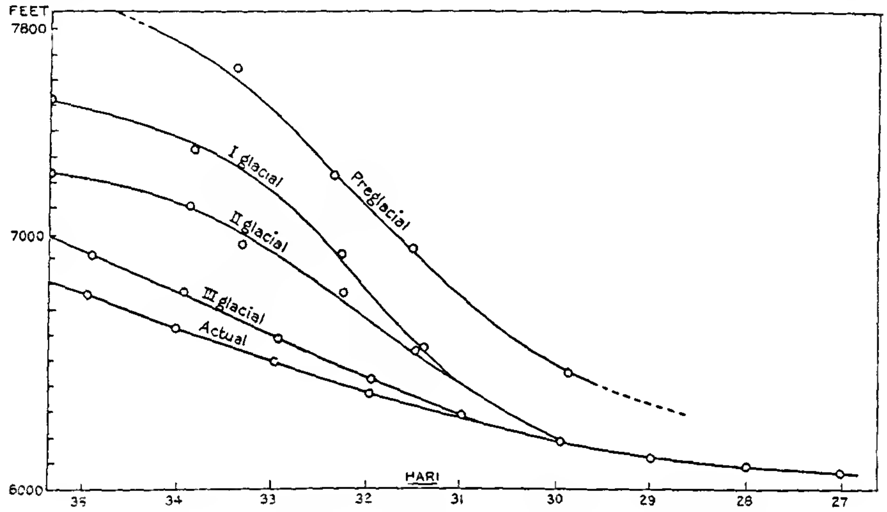


FIGURE 30.—Thalweg forms of various ages between Mamar and Gund.

floor (pl. VI, 1), and so this form is assumed to be of first glacial age. The lower form is 150 feet in depth, and, besides a striated floor, there is a portion of a typical roche moutonnée truncated by a 350-foot nonglaciated cliff which reaches the river. Within the roche moutonnée there are preserved some large erratics as much as 15 feet in diameter, immersed in a brown granular clay. This lower form is assumed to be of second glacial age. Below Sumbal the second form is over 400 feet above the river, and the first form 600 feet. Here also the 400-foot cliff is nonglaciated, and against it rests third glacial outwash. At Pharao, however, this lowest part of the profile, though steep, is troughed, and against it lies the Pharao moraine, of third glacial age.

Above all these glacial trough forms there is a series of distinct "nicks" in the valley profile, which represent the dissected remains of a preglacial valley. This preglacial form is also plotted in figure 30, which indicates the thalweg slopes

[1] The extreme likeness in color of this late denudation product to that of the early second interglacial clay sometimes led to confusion in the lower Sind in estimating the depth of the Upper Karewa lake. Most probably it was such a denudation product which supplied the interstitial yellow-brown clay of the third glacial scree and solifluxion deposits, and a variety, ground by glacial action, which was laid down as the Upper Karewa clays.

of the various ages between Mamar and Gund. (On fig. 30 the horizontal co-ordinates are given as the mileposts on the Srinagar-Ladak road.)

The present thalweg is smooth but begins to steepen at Hari, between mile-posts 31 and 32. The third glacial thalweg is also smooth and is confluent with the present one about milepost 31. However, the second glacial thalweg rises steeply between posts 31 and 33, flattening out beyond. The first glacial bears the same relation to the second glacial as the third to the present, but the first is also abruptly steepened from post 31 to 33 and flattens out beyond. Both first and second forms coalesce and drop to the present valley floor near post 30; hence it can be assumed that below this post the valley is essentially preglacial. An old preglacial floor lying still higher also seems to have been steepened abruptly from post 30 to 33, but beyond that it does not run parallel to the later floors but is somewhat steeper.

Some conclusions may be drawn. If the sudden drop of the river beds of the early periods in this region had been due to a variation in hardness of local rock and production of ice falls, then it would have been highly probable that the prolonged erosion periods indicated between the preglacial and the first forms and between the first and second would have smoothed out the river bed and reduced it to a curve of the types shown for the third and the present forms. The parallelism of the preglacial, first, and second curves, with the distinct distortion mainly between posts 31 and 33, in contrast to the smooth character of the later curves, suggests that the mechanism so distorting the curves was in action principally in second interglacial time. It has been shown, moreover, that the channel between the second and third floors is, below Pharao, certainly due to fluviatile erosion. The form of the profile between the preglacial and first curves is also mostly fluviatile, only the lower portion being glaciated. Naturally the difference between the third and present curves is due to fluviatile action too. Between the first and second, however, the whole of the profile is U-shaped. It can be seen that the first glacier, which was almost as big as the second, did not incise a U shape into the bottom of the immediately preglacial profile. Furthermore, since the first curve bears the same relation to the second as the third bears to the present, then it is not too great a step, in view of the fact that the rest of the profile was eroded by water action, to suggest that the first-second profile was also eroded in a similar fashion, being subsequently completely sculptured by the second glacier, whose ice was thick enough to fill the whole of the channel. This leads to the conclusion that here almost 900 feet of rock have been removed since first glacial time.

The distortion of the earlier curves does not seem to be due to fluviatile processes, which produce types such as the third and later forms. It is suggested that in this region there is a zone of uplift and tilting bordering the main mountain masses, and that during the second interglacial period there was extensive uplift, distorting the early thalweg forms. As the curves flatten out beyond the distorted portions the uplift seems to be in the nature of block rising associated with tilting. Above Gund the third profile again merges with the present form; hence the erosion between third and present time is probably due principally to local

uplift; and, by analogy with this late system, it can be assumed that during the first interglacial time there was some similar uplift and erosion. These erosion phases of the first, second, and third interglacial periods have already been remarked in the analysis of the terraces of the lower Sind. The depth here of the second interglacial erosion contrasted with the depths of the first and third is comparable to that of T1 contrasted with T2 and the scarp between T2 and T3. That the second interglacial phase may have been associated with increase in precipitation, however, may suggest that the second interglacial period was not quite so much longer as the difference in thalweg curves here would indicate.

There is much evidence otherwise to support the hypothesis of uplift of the region beyond Hari, especially in the distribution of topographic forms. A similar boundary to a rising block has been found to the southeast, in the Liddar Valley, and the continuation of the line corresponds to a belt of uplift in the upper reaches

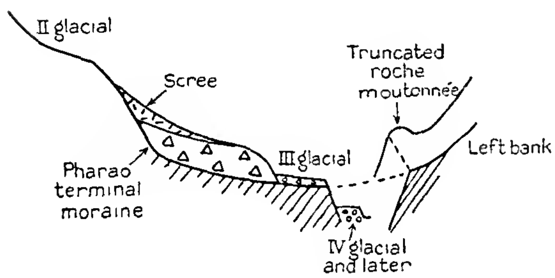


FIGURE 31.—Transverse section at Pharao.

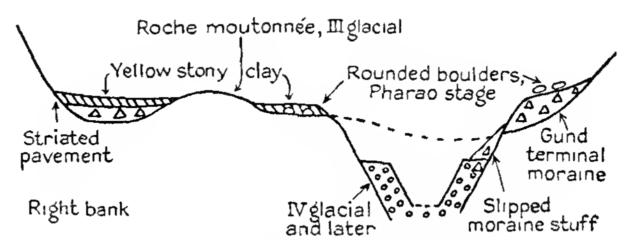


FIGURE 32.—Transverse section at Gund.

of the Chenab Valley described by Norin (1926, p. 285). A more intensive study of the tectonic and physiographic problems will be published separately.

Third glacial period.—The third glaciation is represented by four moraine belts, all lying in the middle Sind. The first advance produced the Gund moraine, at 6,800 feet (figs. 28, 32, and 35). Here, at Gund, about 200 feet above river level, is a well-marked glacial trough with roches moutonnées in the floor. In hollows and plastered against the side of the valley on the left bank are the remains of the terminal moraine, half a mile wide (fig. 32). Scree has issued from a deep lateral valley on the right bank and immersed the moraine, which is characterized by large angular boulders in a grayish-yellow matrix. There are rounded blocks at the bottom and on the surface. Where the scree has not obscured the moraine entirely a yellow stony clay can be seen rather like the moraine matrix. It is thought that this is not a later deposit, but either débris of the boulder clay or rock decomposed in place, for parts of it appear very stony, with sharply angular fragments.

Banked up against the moraine is an outwash boulder conglomerate of very coarse facies, and this, as well as the moraine, is cut by a steep erosion channel in which lies terraced reassorted conglomerate. The first conglomerate can be seen downstream in the river walls, overlain by deep scree, which is also cut by the erosion channel; and it is this conglomerate that seems to underlie, as a basal bed, the Pharao ground moraine. The conglomerate is construed as outwash

of the Gund moraine ice (fig. 35), and this, together with the deepening of the Gund trough by glacial action (fig. 32) and the rounded boulders on the surface of the moraine, points to the Pharao ice being later than the Gund. How much later is impossible to determine, but it cannot have been long after, or the third glacial terrace gravels of the lower Sind would have shown greater rhythmic variation.

The Pharao moraine at 6,600 feet, on which the village of Pharao is built, is more easily outlined than the Gund moraine, as it has not been eroded by subsequent ice. It is three-quarters of a mile wide, is similar in composition to the Gund moraine, and is, in part, covered by fan material from Pharao Nar. Overlapping and in front is an outwash conglomerate, and, with the moraine, this is cut into by two terraces of 100 feet and 10 feet. The present exposed thickness of the moraine is almost 80 feet and stands about 100 feet above river level. The moraine and the trough in which it lies have been deeply eroded, and the present

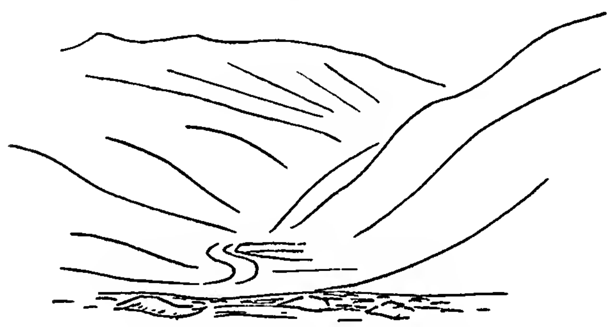


Figure 33.—View downstream from the Gagangiyer moraine. Rezan moraine in valley bottom. Oversteepening is marked on right bank, and above are truncated remains of an earlier glaciated floor.

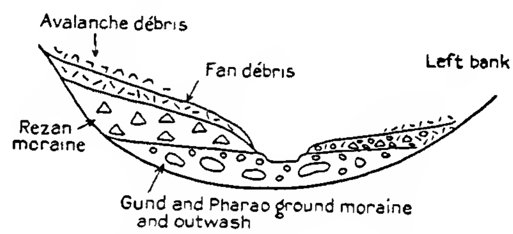


Figure 34.—Transverse section at Rezan terminal moraine.

river runs in a gully which has even cut into the solid rock, for just above Pharao, on the left bank about 100 feet above river level, a portion of a roche moutonnée, which seems to have lain in the original third glacial trough, has been truncated. This truncation can be seen at various heights along the river and is expressed in figures 29 and 30. The remains of the first and second glacial floors are very well exposed at Gund, on the right bank on each side of the moraine. On the road at Pharao village a large boulder is exposed lying in the third glacial outwash. This is composed of a hard cemented angular breccia of limestone and comes from a deposit in Sonamarg. A similar boulder occurs in the Pharao moraine. These erratics are interesting, for they are the main indices of the age of the original material.

Up from Gund the valley widens and the river runs in the third glacial floor (fig. 36). This widening, according to Oestreich, is due to glacial action, but it may have been already defined in preglacial time, as there is a marked amphitheater high on the hillside above. (See fig. 33, the high, gently sloping region in the far background.) The narrow, almost gorgelike character of the Gund-Mamar portion of the valley is due to rapid erosion across a rising area, just as the Gagan-

giyer Gorge (see below), cut through a rising range, is backed by the wide valley of the Sonamarg, which was determined in a preglacial epoch. In figure 35 it can be seen that the thalweg rises rapidly between Pharao and Gund, flattens out above Gund, and then rises toward Gagangiyer. If the ice had widened the valley, then it would be expected that such glacial erosion would have been continued at least as far as Gund, for the ice stretched to that point and beyond.

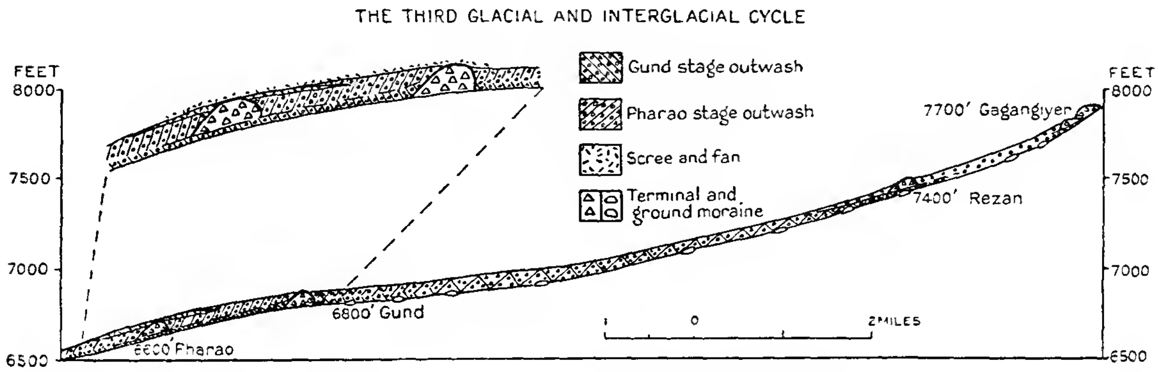


Figure 35.—Longitudinal section, Pharao to Gagangiyer.

Figure 36.—View downstream from a point 1 mile below Rezan. On the left is a glaciated spur 250 feet high, the top of which probably formed part of the floor for the second glacier. It is now thoroughly striated. Oversteepening on the right due to the third glacier.

In the valley floor the stream bed and terrace conglomerates are littered with huge erratics, presumably the relics of the third glacial ground moraine. The conglomerates are coarse and heterogeneous and are continuous with and like the conglomerates of the lower moraine belts. It is difficult to determine their ages, but there are two terraces, the higher one at about 80 feet, badly defined, corresponding to the higher conglomerate terrace at Pharao (fig. 31), and the lower one composed of reassorted material with gray, dusty-brown interstitial silt like that of the lowest terrace in the lower Sind.

At Rezan, at 7,400 feet, over 6 miles above Gund (fig. 35), conglomerate and ground moraine are seen to lie at the base of the Rezan moraine [1] (fig. 34). The lower limit of this material is arcuate, but the upper or inner border is obscured by

[1] See Norin, 1925, p. 170.

much fan débris from a small gully in the right bank. This fan is lighter in color than the moraine and has much smaller boulders. It is, in the main, fairly old, being covered by modern avalanche débris. The moraine itself is only a third of a mile wide. On the left bank the moraine has been almost completely removed by wash from a side valley, and the erratics are mixed with scree.

Midway between Rezan and Gagangiyer, on the left bank, there is exposed indistinctly but fairly uniformly stratified creamy-yellow clay with angular and subangular boulders. The bedding is curved longitudinally with respect to the river and is convex upward. This attitude and the lack of big boulders suggest a fan origin from the large side valley which debouches here. Here and there in the middle Sind there is difficulty in determining whether a deposit is a fan or a moraine, as the true moraines are themselves obscured by fans. There are, however, several points on which a decision can be based—namely, the large size of the boulders in a moraine, their heterogeneity of provenance, their occasional faceting, the arcuate outline of a moraine, and the lack of any stratification whatsoever. Three out of the four moraines of the third age have been formed almost opposite side valleys, and it is probable that the glacier, losing its forward momentum, was unable to cross the height of the fans emerging from the valleys. Such fans may have been formed on a large scale as the strenuous conditions of the third glacial period approached.

The Gagangiyer moraine, at 7,700 feet, is composed of a collection of large angular and subangular blocks stretching down for over a mile from Rosanyil, at the mouth of Gagangiyer Gorge. At Rosanyil itself 200 to 300 feet of morainic débris can be seen on both sides of the river. There seems to have been a piling up of several moraines, but there are two main masses (fig. 35). The moraines themselves have had much of the interstitial débris removed by the torrent of the river which emerges from the gorge, and the greater part of the outwash too has gone, leaving only isolated patches. Beyond the Gagangiyer moraine intensive erosion and much scree formation have obscured all details.

It is possible that there may have been a retreat stage or minor advance of the third glacier to a point opposite Vichmargi, above Sonamarg (fig. 41), for at that point there is a belt of what seems to be morainic débris of older topography than the fourth moraine, with third interglacial conglomerate banked against it.

Gagangiyer Gorge is about 2½ miles long. The river bed drops 500 feet in this distance, forming a cataract that plunges between steep walls which tower 4,000 feet above the water and are separated at the top by little more than a mile. The steepest portion is at the bottom, and this, it is believed, was eroded during successive glacial and interglacial periods, for the remains of the valley floors preceding third glacial time approach the gorge high above the present river (fig. 33). In the gorge itself there is a glaciated floor remaining 700 to 800 feet above the river bed, which may be the continuation of the pre-third forms. A still higher break in the profile, about 2,500 feet above the river, does not seem to be glaciated and may be preglacial. Moreover, in the Sonamarg Basin (fig. 39) the second interglacial fan breccia indicates that the level of the water filling of the

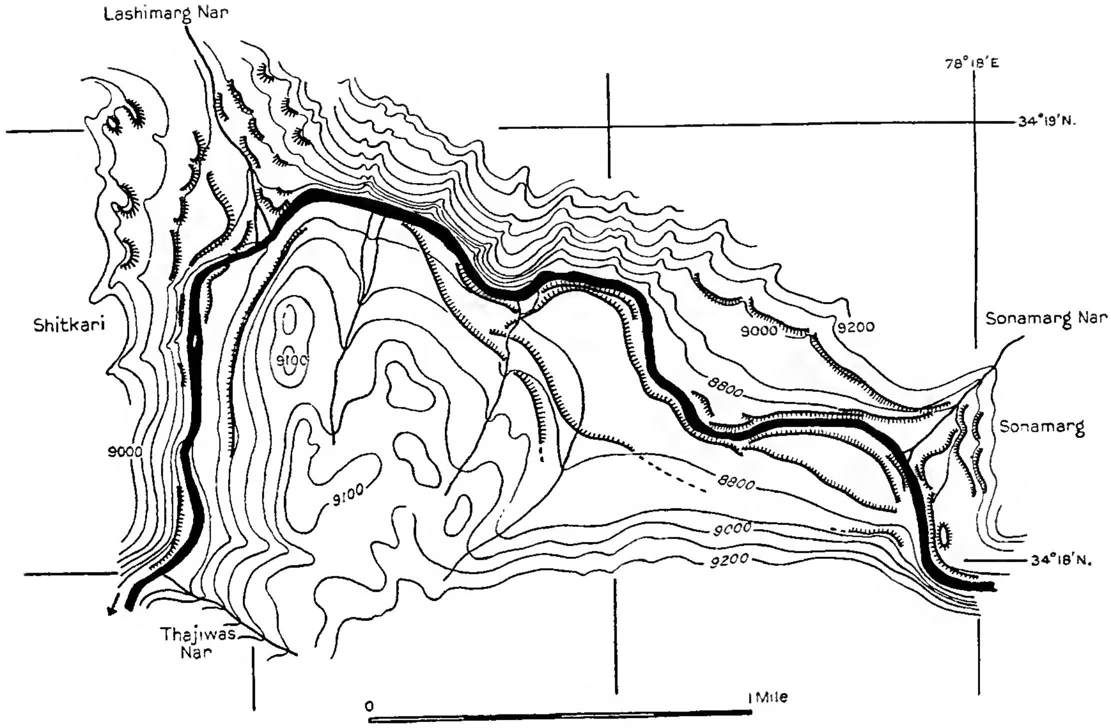


FIGURE 37.—Map showing the Sonamarg terraces (dentate lines).

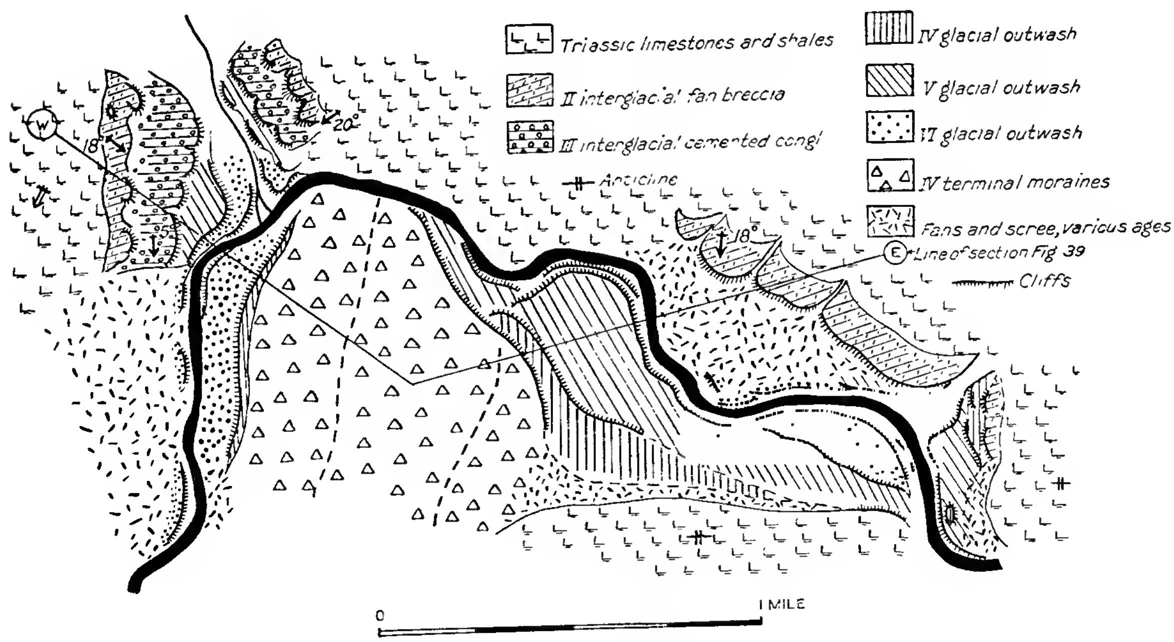


FIGURE 38.—Map of the Sonamarg Basin.

basin stood at about 9,400 feet (if it is assumed that the bedding of the breccia was produced as the fans descended into the basin and were cemented there by the calcareous waters of the lake). Therefore the gorge outlet of the lake must have been at more than 9,400 feet in contrast to the present-day 8,500 feet. It is unlikely that a moraine dammed the lake during the considerable period of time represented by the fan breccia, because moraine stuff would have been quickly denuded. The river did not drain off in any other direction than the present valley; therefore the damming back of the lake must have been due to uplift of the Ogput Range during early second interglacial time. There seems to have been a repetition of the Hari-Gund uplift, for the river bed rises sharply 2 miles beyond Rosanyil and then flattens out again.

Upper Sind

The upper section of the river can be divided into the Sonamarg Basin and the Baltal Valley, which stretches up from Sonamarg. The Sonamarg, as its name

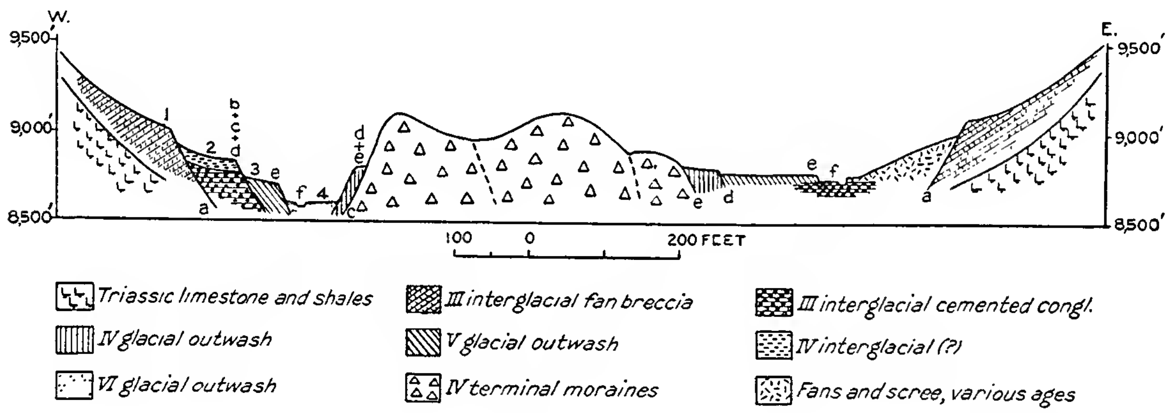


FIGURE 39.—Transverse section across the Sonamarg Basin. 1, 2, 3, 4, terraces. For explanation of a, b, c, etc., see text.

implies, is a wide, spacious upland valley (pl. VI, 2) and contrasts strongly with the narrow steep-walled Baltal region (pl. VIII, 1). The four glacial moraines are congregated in the Sonamarg region. Later moraines and a retreat-phase moraine of the fourth glaciation lie in the Baltal Valley.

Sonamarg Basin.—The valley of Sonamarg (fig. 38 and pl. VI, 2) is roughly triangular in shape. The base of the triangle, about 1 mile in length, lies to the west, and the apex to the east, about 2½ miles distant. The river enters at the apex and circles the north side and the base. At the two angles of the base the Sind is joined by the Lashimarg Nar on the north and by the smaller Thajiwas Nar on the south. At the apex the main river is also swelled by the waters of the Sonamarg Nar, draining two large valleys north of the village.

The whole valley is anticlinal (figs. 38 and 39), cut into folded Triassic shales and limestones, mostly the latter, of silver-gray color (pl. VII, 1). The floor of the valley is a smooth concave trough, shallow and easily cultivated. At the west end, however, the valley rises in small hillocks (pl. VI, 2) some 300 to 400 feet in height composed of morainic material from which enormous blocks weather out

on the surface. The river has cut into this moraine at the north end of the base, where the entry of the Lashimarg Nar caused a weakness. The rest of the valley floor is composed of fluvioglacial material, which has been laid down during periods of erosion and deposition and thereby terraced. The terraces, complicated in the later stages by small meander terracing, are wide in the upper part of the basin but narrow and deep in the lower part, where the river cuts its bed between the moraine hills and the rock to the west. At the apex of the valley the two spurs guarding the entry of the river are smoothed and U-shaped. Figures 37, 38, and 39 illustrate the topography and geology.

Above the basin, and especially well marked on the north side, are two series of old valley forms, now thoroughly eroded by deep gullies. These forms may be the remains of early glacial or preglacial valley bottoms. On the flanks below these spurs, resting on the eroded up-tilted limestone (pl. VII, 1), is a breccia of distinctive kind, composed of angular fragments of limestone, some pieces as much as 2 feet across, very coarsely bedded, steeply foreset, and, on the whole, very reminiscent of fan material. The angle of dip at the small U-shaped bend in the river in the middle of the basin is 18° (fig. 38); lower down, above the junction of the Lashimarg Nar, it is 20°, and opposite the moraines again 18°. There are no rolled boulders or pebbles, and the elements are entirely limestone.

Erratics of this cemented fan breccia occur in outwash and moraines of the Pharao and Gund stages of the third glaciation. Therefore the breccia precedes that glaciation in age. It may be thought to be of the same age as the first glacial conglomerate, which was cemented in a similar fashion, but it has not suffered the erosion that would be expected by passage of the second glacier. It has been shown that the basin was inundated by damming due to uplift immediately succeeding the second glaciation, a movement also strongly marked at Hari. The period of marked erosion during the long second interglacial period cut Gagangiyer Gorge deeper and so drained the lake. Hence the age of the fan breccia is second interglacial, at the beginning of the later stage of that period—that is, almost of an age with the basal conglomerate of the late second interglacial aggradation deposit of the lower Sind.

The latter deposit shows signs of solifluxion, and it may be that the great quantity of angular débris in the fan breccia of this age is due to greater denudation following a more rigorous climate. The fan breccia, after draining of the lake, was cut into (fig. 39, a) by continuation of erosion during the latest portion of the second interglacial period. This erosion produced the escarpment fronting the highest 400-foot terrace 1 of Shitkari.

The question of cementation is of interest. The breccia was cemented because the lake waters were saturated with calcium carbonate derived from the limestone locally. The first glacial conglomerate was cemented because the ice was eroding Triassic material at the head of the valley, and the second glacial conglomerate was not cemented, presumably because, during the first interglacial period, the river had cut its way through the Triassic to noncalcareous rocks and the waters would have been as they are today. When the second interglacial Sonamarg Lake was drained, then a fair quantity of calcium carbonate would have been liberated.

This would then account for the concretionary bands in the late second interglacial deposit of the lower Sind.

After the latest second interglacial erosion the third glacier advanced down the valley, carrying off blocks of the breccia as erratics. Dainelli noted boulder clay 170 meters above the valley floor on the left bank above Sonamarg. As the moraine walls of the fourth glacier do not reach this height, it is improbable that such boulder clay represents a lateral moraine of the fourth glacier. It may be of third glacial age, for that glacier was more powerful and probably thicker. However, there is better evidence for the third glacier in the presence of striated and faceted boulders at the base of the conglomerate (described below) to be seen at the junction of the Lashimarg Nar with the Sind.

This cemented conglomerate was noted by both Dainelli and Norin as underlying the moraines. In contrast to the second interglacial fan breccia it is composed of water-worn boulders cemented in a yellow clay matrix and like the Malshahibagh conglomerate in appearance. The boulders are small and homogeneous in size except at the base, as noted above. Moreover, the conglomerate almost everywhere approaches the horizontal in its bedding, having a dip of 5° downstream at a spot half a mile below Sonamarg and a smaller dip downstream opposite Shitkari (pl. VII, 2, and fig. 38). It cannot be a basement to the breccia, because the dip angles represent a strong unconformity; and it must be later than the breccia, as the mapping indicates. The homogeneity of the boulders, except for the basal beds, suggests an origin not as outwash, but fluviatile, with the glacier front some miles upstream, just as the Malshahibagh conglomerate at Gandarbal is fine and homogeneous. The conglomerate is older than the fourth glacial moraine and younger than the third glacial, hence it must be third interglacial. It can be traced in the bed of the river as far as Baltal and beyond (fig. 41) underlying the various late moraine belts. Figure 39 shows that the height of this conglomerate at Shitkari is not much less than that upstream; therefore the gradient was much less at the time of deposition than it is now. Perhaps, indeed, the Gagangiyer barrier was still fairly high, or else, on analogy with the Hari area, there has been later uplift and tilting. Erosion, possibly due in part to this tilting, excavated this cemented conglomerate, for the fourth moraines lie in a channel in it (fig. 39). Regard must be had to the possibility that such erosion may have reduced the level of the conglomerate in the upper part of the basin, hence giving the appearance of less gradient in the early third interglacial thalweg; but as the level seems to be continuous upstream, the argument for erosion caused by tilting still holds.

The fourth glacier advanced and deposited moraine stuff at the entrance to Gagangiyer Gorge (8,500 feet). The moraine, composed of large angular and subangular boulders with many angular pebbles, in a gray-yellow clay matrix, is at Shitkari (pl. VI, 2, and figs. 37, 38, and 39) over 300 feet thick and seems to be composite. It is drained by two small streams, which flow in hollows between three transverse masses of moraine that still retain in great part their original topography. It may be that there are three moraines here (indicated on figs. 38 and 39 by dotted lines) piled one against the other, but there is no conclusive evidence,

for any intermediate conglomerates which may have been formed here are now covered, or, where the river has cut into them, have been eroded and subsequently concealed by a later conglomerate. The last stage of the fourth glaciation to be seen is a moraine at Nilagrar, 2 miles above Sonamarg (figs. 40 and 41), overlying the third interglacial conglomerate and overlain by a fifth terminal moraine of much fresher appearance.

The moraines at Sonamarg must have dammed up the entry to the Gagangiyer Gorge, but the Lashimarg was able to run between the moraines and the rock on the west and excavate a channel with the assistance of the glacial waters of the Sind, which joined the Lashimarg at the north end of the moraines, where the barrier was most easily broken down. This was the period when the river course was fixed as it is at present, except for wide terracing in the upper part of the basin. This glacial erosion (fig. 39, c) continued and deposited in the deep channel of Shitkari, and in the space above the moraines, glaciofluvial outwash which is distinct because of its composition of ungraded conglomerate carrying large rounded and subangular boulders in a matrix of yellow to gray sandy clay. It is this material that forms the 100-foot terrace on the left bank at Shitkari, on which runs the main road, and the highest terrace on the left bank above the moraine.

Some small loose gravels which lie on the surface of the 250-foot terrace 2 at Shitkari may belong to the fourth interglacial period, for they were truncated by the next erosion phase (fig. 39, d), correlated with the fourth ice advance. This erosion was intensive, removing a great part of the fourth outwash conglomerate above the moraines and leaving that outwash only on the left bank at Shitkari. This erosion phase was succeeded by an aggradation period of the same or partly the same age, when extensive conglomerates were laid down—those of the 100-foot terrace at Shitkari and the broad main terrace opposite Sonamarg village across which runs the Ladak road. This conglomerate is easily distinguished from the fourth glacial conglomerate, as the boulders are more graded in size, very few of them large (and these may be derived from the earlier deposit), all very water-worn, few of them subangular, and there is less clay matrix. This conglomerate can be traced up to the fifth terminal moraines, which it envelops, and the terrace itself dies out between Sonamarg and Baltal. Hence the conglomerate is correlated with the fifth ice advance.

The 100-foot Shitkari terrace was then truncated during another erosion period (fig. 39, e), which, though cutting deeply at Shitkari, cut only 20 to 30 feet in the region above the moraine. This erosion was succeeded by the deposition of well-rolled and fairly fine conglomerate. The rate of deposition was not much greater than that of today, the only aggradation of note being the 20 feet of gravels on which the village of Shitkari is built. These terrace gravels, cut into (fig. 39, f) by the present river, can be traced beyond the fifth moraines and may be due to a very late sixth readvance of the ice in the reaches above Baltal.

Plate VI, 2, shows an interesting phenomenon in the tilting of the latest terraces in a northeast direction.[1] It may be that tilting in the same direction has

[1] This tilting has been measured, but the figures are reserved for a later research on tectonics.

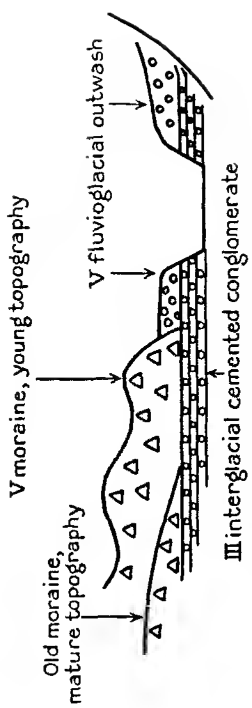


FIGURE 40.—Section 2 miles above Sonamarg.

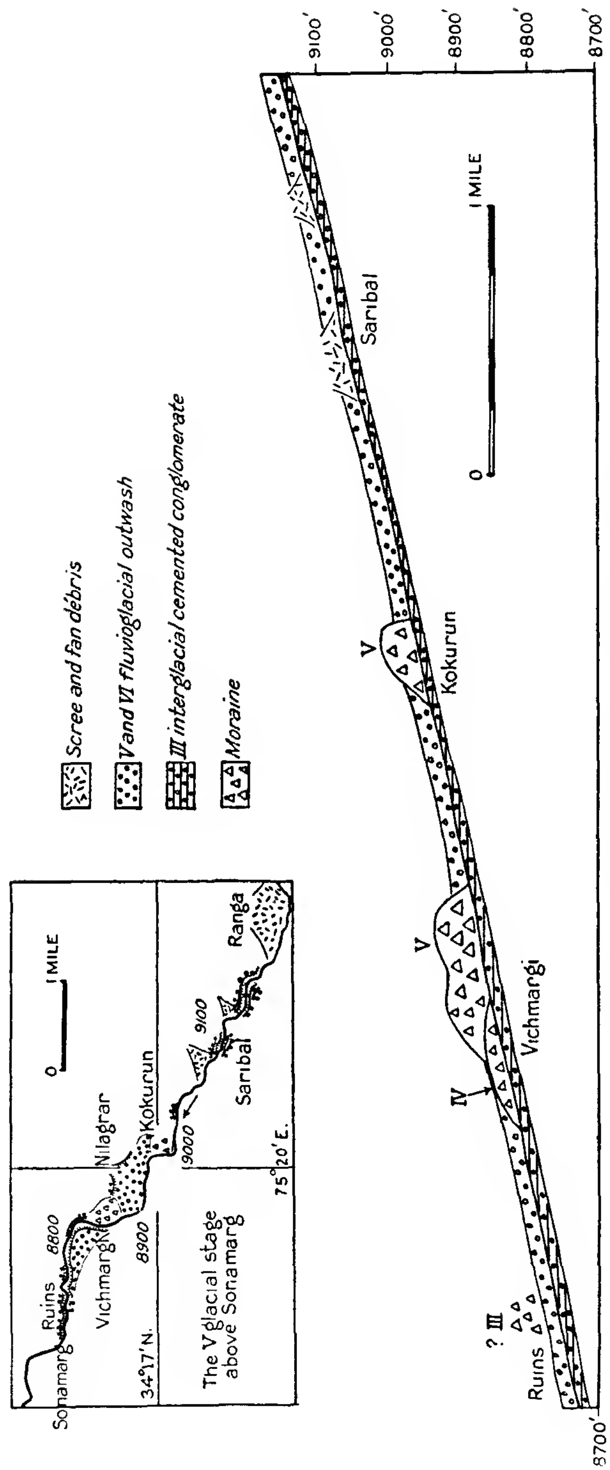


FIGURE 41.—Longitudinal section and map, Sonamarg to Ranga.

been continuous since second interglacial time, thus accounting for the depth of channeling along the Shitkari portion of the river, which runs north-northeast, in contrast to the more shallow cutting in the upper part of the basin, where the river runs at right angles to that direction. The tilting, as it affects the lowest terraces, seems therefore to have continued down to recent time. It is this direction of tilting which may account for the great development of large fans on the north side of the Baltal Valley (fig. 41), whereas there are few, and these small, on the south side.

Baltal Valley.—At the point marked "a" on plate VIII, 1, just beyond the ruins (fig. 41), the late gravels of the sixth advance can be seen to overlie disconformably third interglacial cemented conglomerate. At "b" is a long slope made up of morainic débris, 250 feet thick, with a topography older than that of the fourth moraines. Its relation to the third interglacial conglomerate cannot be seen, but, as suggested before, it may be the moraine of a readvance or a halt stage in the retreat of the third glacier. The terrace at "c" shows much outwash material of fifth and sixth age, and 500 feet above, at "d," there is a small patch of second interglacial cemented fan breccia clinging to the walls. At "e" there is a hillock of moraine with more mature topography than the terminal moraine of Nilagrar ("f"), which overlaps it (fig. 40). The moraine ("e") rests on coarse third interglacial conglomerate and seems thus to be of fourth glacial age, while the very fresh moraine ("f") must then be later than fourth glacial. At "g," at the bend below Kokorun (fig. 41), there is another terminal moraine. The matrix is entirely a fine gray powder interstitial to enormous angular blocks of limestone. The outwash related to this moraine is banked against an erosion face cut through third interglacial conglomerate overlain by outwash conglomerate that is connected with the Nilagrar moraine. Hence there seems to have been an erosional period between the Nilagrar and Kokorun phases, though these probably belong to the same fifth glacial period.

Between Kokorun and Saribal on the right bank there is a fairly large fan deposit overlying third interglacial conglomerate. The fan is composite, for a layer of large boulders marks off a lower from an upper portion, which is much looser than the lower. The boulders have protected the underlying material, and some excellent examples of rock pillars have been formed. Both portions of the fan have been truncated by erosion, and two terraces of conglomerates have been laid against them; therefore the age of the fan as a whole is fourth interglacial, with the layer of boulders perhaps marking a climatic oscillation in that interglacial period. Opposite Saribal there are several well-preserved roches moutonnées. (See fig. 41.) At Ranga there is an old fan (probably of fourth interglacial age too) cut by a newer fan which in turn is cut by the lowest sixth glacial terrace. This newer fan may be thin fifth interglacial.[1] Beyond Kokorun the valley bottom is filled with much bottom moraine and it is difficult to determine further stages of ice advance. The Liddar Valley yields more evidence.

[1] The word "interglacial" may, in referring to these recent and subrecent oscillations, be equivalent to "intraglacial."

Plate VIII, 1, shows at "h" the greater part of a U-shaped trough lying about 2,000 feet above the valley floor. If this trough is assumed as first glacial, the subsequent erosion was, in the main, fluviatile, as shown by the valley profile, and not glacial in origin.

GLACIAL SEQUENCE IN THE LIDDAR VALLEY

The Liddar is the next river to the east of any consequence, and a traverse was made in order to check up on the succession which had already been worked out for the Sind Valley. The Liddar (see pl. LV and fig. 42, also 1-inch maps of Indian Survey 43 N/8, 43 O/1, 43 O/2, and 43 O/3) is not as long as the Sind but derives its waters from the same portions of the watershed. In its upper reaches, beyond Pahlgam, it is twofold, the West Liddar draining part of the Kolahoi Glacier system, and the East Liddar draining the lake of Shishram Nag, which lies at the foot of Saskat, on the opposite side to that whereon the Sind is born.

The Liddar Valley can conveniently be divided into two portions, the upper and the lower. The lower Liddar stretches from Pahlgam downward, and the following text includes a description of a part of the main Kashmir basin as far as the junction of the Liddar with the Jhelum. The lower Liddar is the region of deposition and is wide and spacious, with a fairly uniform slope of thalweg. The upper Liddar (East Liddar) stretches from Pahlgam to Shishram Nag (a description of the West Liddar is not included), and here the thalweg is irregular, rising in steps just as the Sind does from Hari upward. The valley, too, becomes narrow and constricted except for the arena of Pahlgam, and in the upper reaches deep gorges are the rule. Deposition has been meager.

Dainelli (1922, chapter 11) visited this valley and made several observations. He noted the effects of glaciation on the slopes between Aish Makam and Pahlgam, the valley opening out below Khelan with a typical glacial profile, and observed the Lioru moraine at the opening of Langinal Nullah. He also maintains that Kanjdori Hill (pl. IX, 1), below Aish Makam, is glaciated, and that the glaciation preceded the formation of the Kashmir Lake, as at Ahateng, at the mouth of the Sind. At the same time he quotes Vigne (1842, p. 22), who observed a cemented conglomerate between Islamabad and Aish Makam, which Dainelli correlates with the Malshahibagh conglomerate, of first interglacial age.

Grinlinton (1928) made a remarkably accurate study of the glaciation of the upper Liddar. He divides the sequence into a high-level epoch of early date and a late low-level epoch which he subdivides into several stages. The first was the Pahlgam stage, when moraines were formed at Pahlgam. After a period of recession of the ice about to the point where it is now, it advanced to Nekabatun, and this advance was followed by a retreat, when the cup of Shishram Nag was filled up. The ice again advanced beyond Shishram Nag, the Mainpal stage, which in turn was followed by a slow retreat, the post-Mainpal recession, marked by pauses and pulsation. Two very minor stages succeeded the Mainpal. It was found afterward that the writer's observations on the upper Liddar agreed with those of Grinlinton, who worked more extensively and with much greater detail; hence the

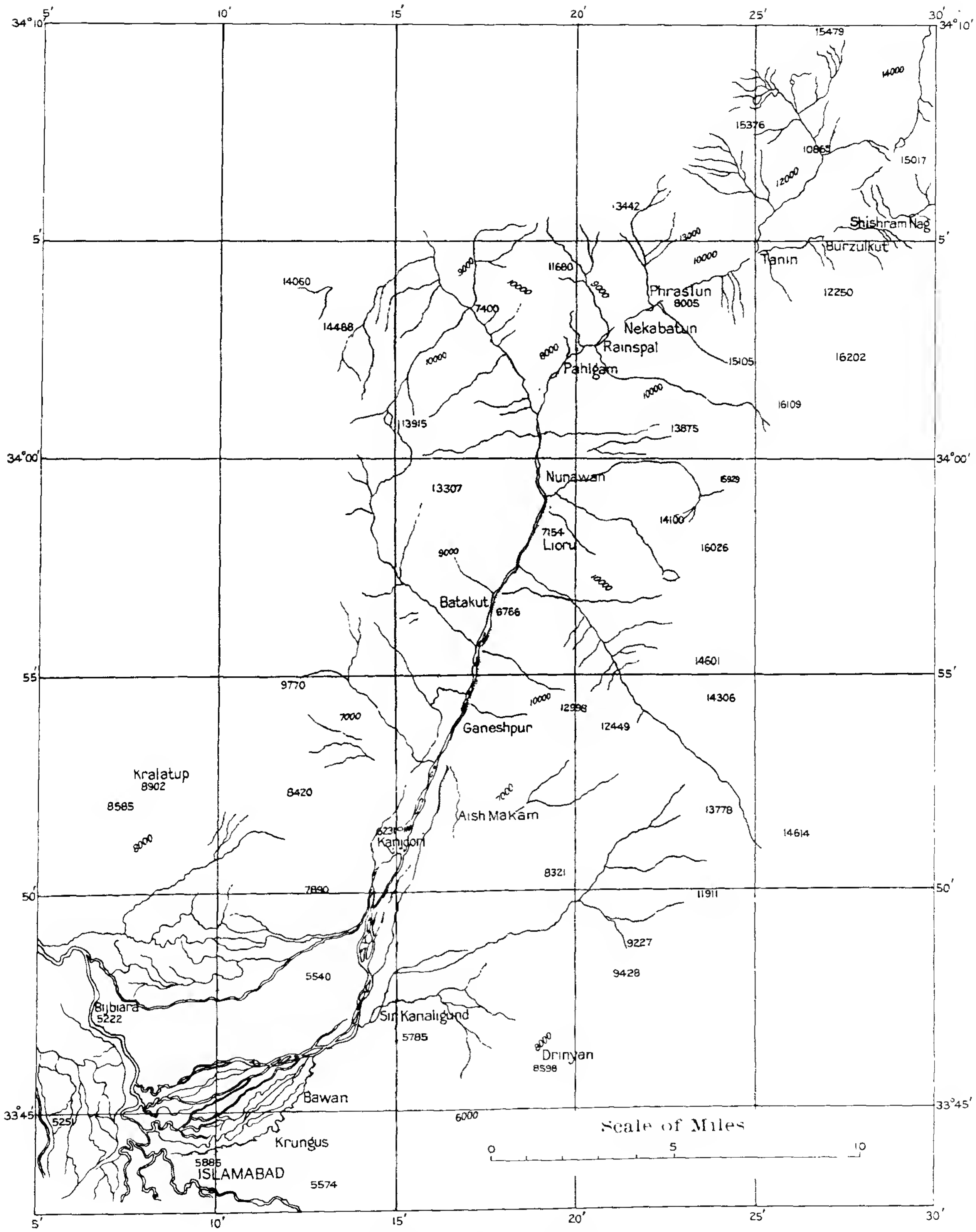


FIGURE 42.—Map of Liddar Valley

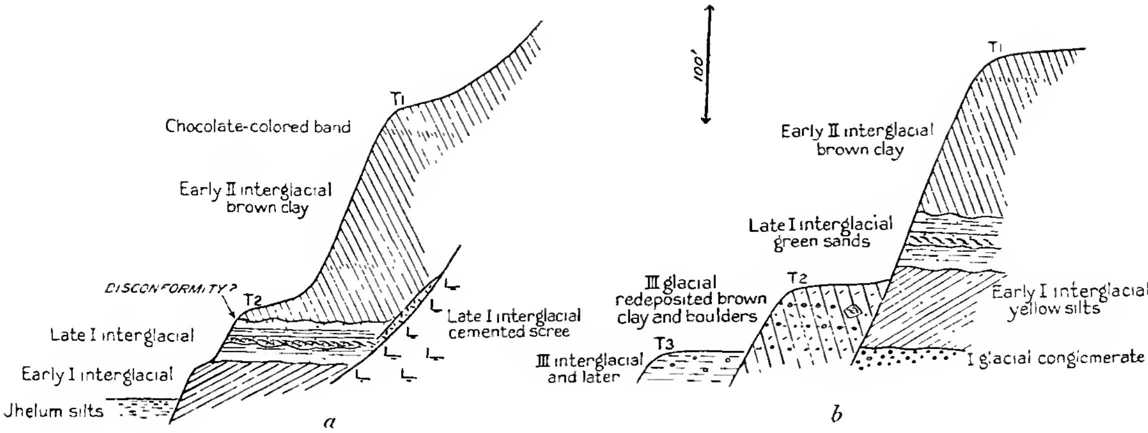


FIGURE 43.—Transverse sections at Islamabad (*a*) and Krungus (*b*).

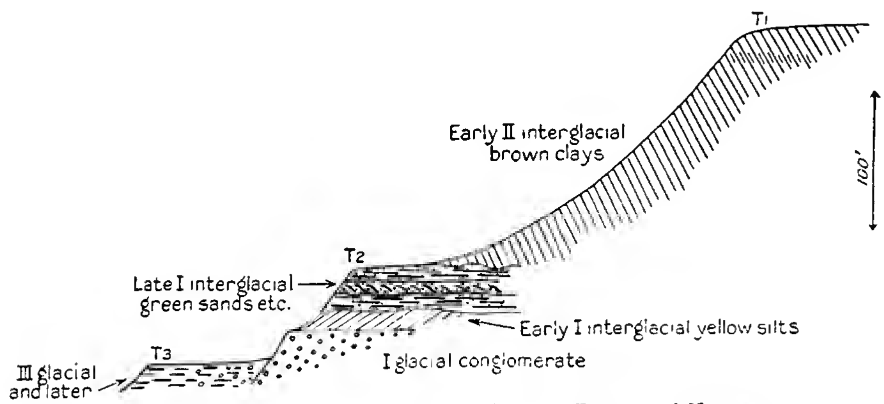


FIGURE 44.—Transverse section midway between Bawan and Krungus.

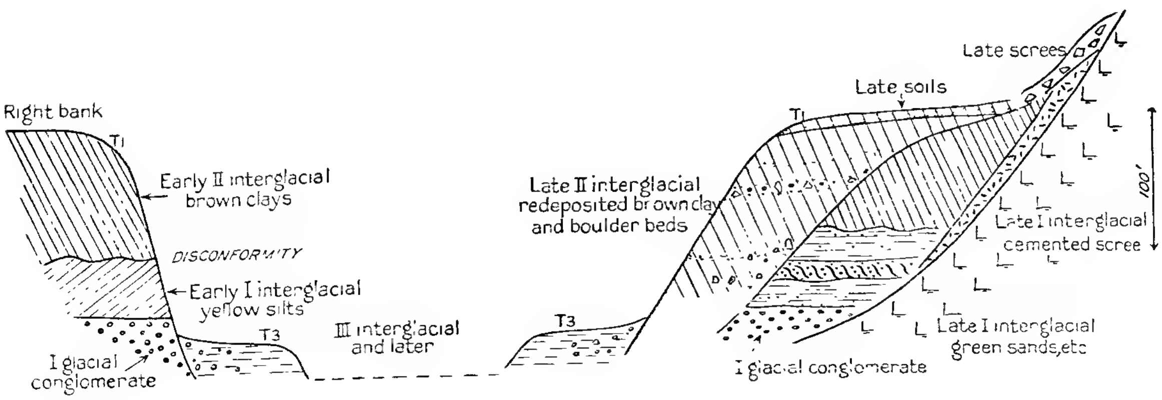


FIGURE 45.—Transverse section at Bawan.

description of the upper Liddar will be only a matter of correlating the results of Grinlinton with the general scheme of the succession.

It is here submitted that Kanjdori is not glaciated. Plate IX, 1, shows the hill from the west. Apart from the tailing away of the slope on the south, all the features can be accounted for by the variation in the material of the rock. Moreover, to glaciate the hill would require a glacier at that point over 5 miles wide and several hundred feet thick, of which there are no signs.

The terrace succession in this valley is not nearly so complete as that in the Sind, but four terraces were found. As in the preceding pages, the terraces will be referred to by number, the height being indicated by a scale in the sections. So also details of physiography and tectonic development will be reserved for a future research.

Lower Liddar

First glacial.—Islamabad stands at the junction of the Liddar and the Jhelum, and just above the town, beyond the hospital, can be seen the lowest occurrence of a cemented conglomerate of exactly the same characters as that of first glacial age at Malshahibagh, at the mouth of the Sind. (See p. 40.) It is better exposed at Krungus (fig. 43, *b*) and can be traced as far up as Kanjdori (figs. 44, 45, 46, and 47). It is not seen to be related to a moraine, but as it is overlain by deposits which are palpably later than the moraine at Ganeshpur, described below, it is assumed to be the outwash of the glacier which produced that moraine, just as the Malshahibagh conglomerate is the outwash of the first Mangom Glacier.

Ganeshpur moraine.—A mile above Ganeshpur, at 6,100 feet, on the left bank (fig. 48, *a*), a terrace of about 200 feet is capped by some avalanche material, which is indicated by the fresh and local character of the rocks. It overlies lower down a brown granular clay (second glacial) and a deposit which is distinct because of the varied provenance of the boulders, angular and subangular, of gray, green, and white quartzite, sandstones, pebbly conglomerates, pudding stones, gneisses, and grits, all in a yellow-brown clay-sand matrix. Boulders as much as 8 feet in diameter occur in this deposit. It cannot have been derived from a valley behind, as it laps a spur, and in the stream bed of the same part there are many massive subangular boulders. This deposit of Ganeshpur is interpreted as the lateral remains of an eroded terminal moraine, from which were derived the blocks of the river bed. It is backed by ground moraine overlain by outwash of the Lioru moraine ice. (See below.) The Ganeshpur moraine is assumed to be of first glacial age, though the evidence for this assumption is not by any means conclusive. Below this region there are no signs of glaciation, but there are such signs above it, though below the Lioru moraine. At Nunawan (fig. 51) all the second glacial material lies in a trough scooped into a floor already glaciated. It is thoroughly eroded, much more so than the Lioru moraine, and it is the only morainic deposit with which the cemented conglomerate could be connected, this conglomerate being separated from the Lioru outwash by extensive interglacial deposits. The ground moraine of the same glacier underlies the Lioru moraine (fig. 50).

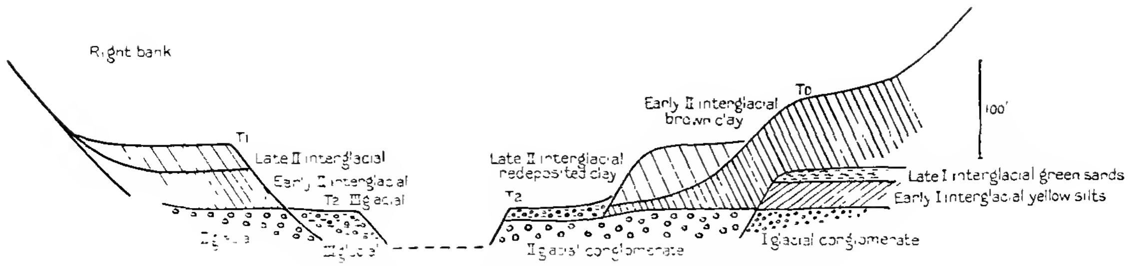


FIGURE 46.—Transverse section in the region of Kanjdori.

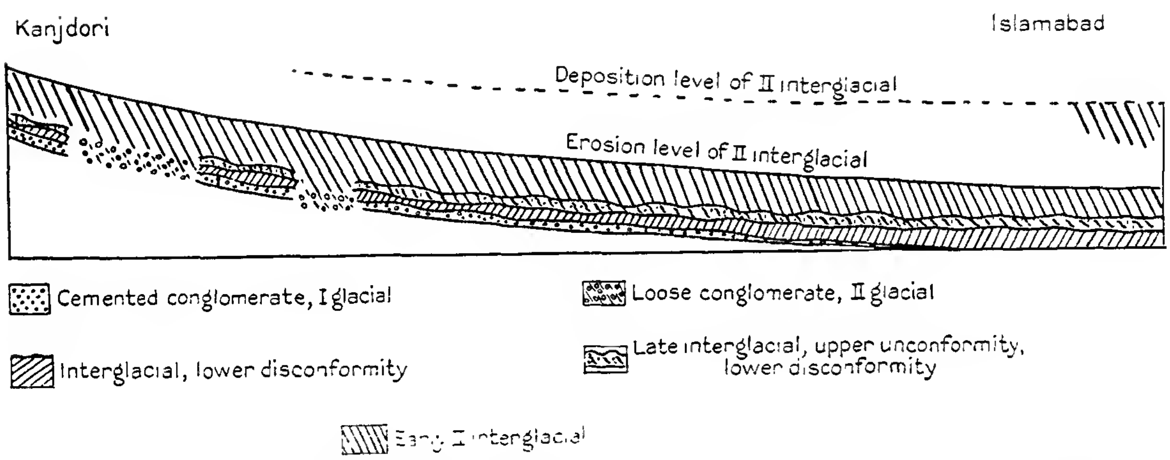


FIGURE 47.—Diagrammatic longitudinal section, Kanjdori to Islamabad, showing relations of various early deposits.

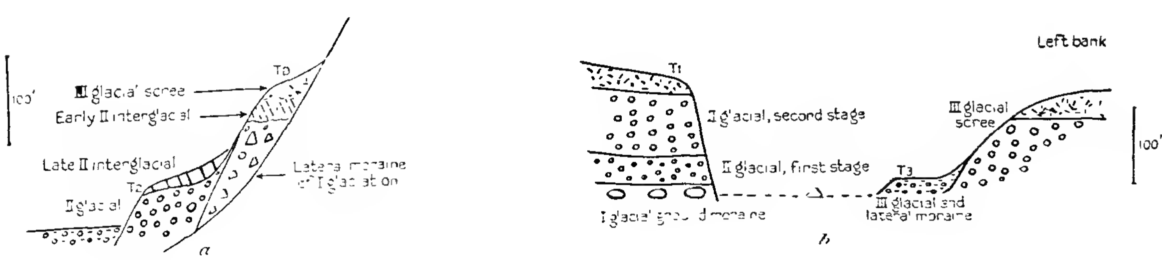


FIGURE 48.—*a*, Section of the left bank of the Liddar at Ganeshpur; *b*, Transverse section at Batakut.

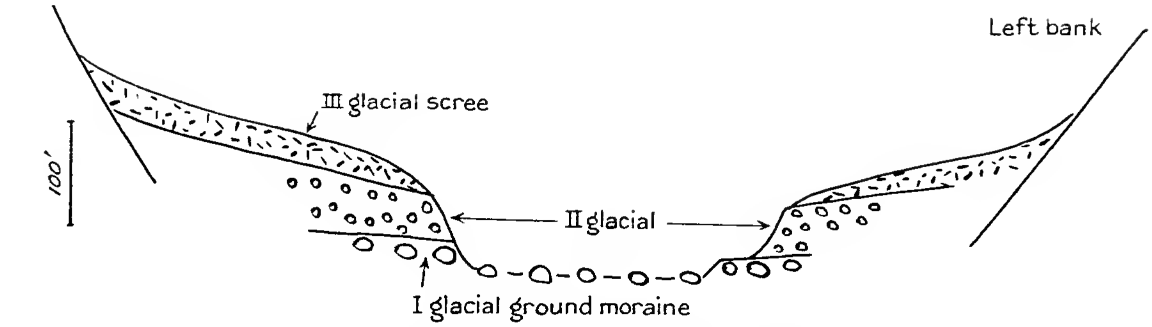


FIGURE 49.—Transverse section below Khelan bridge.

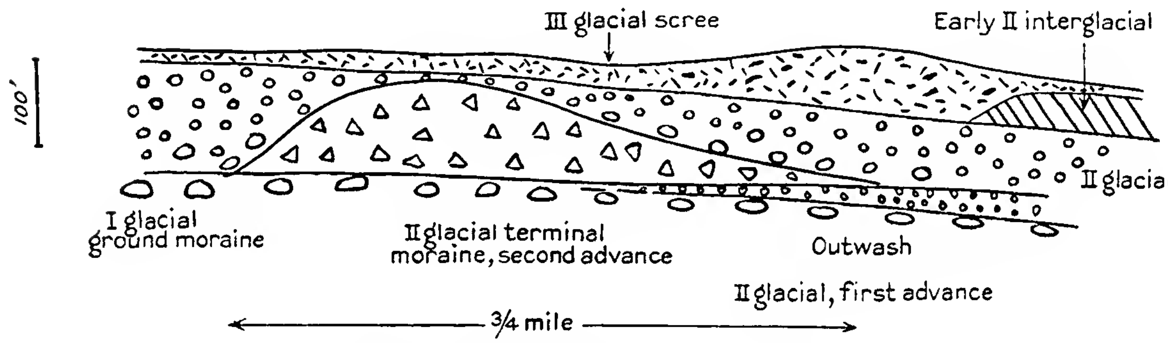


FIGURE 50.—Longitudinal section of Lioru moraine.

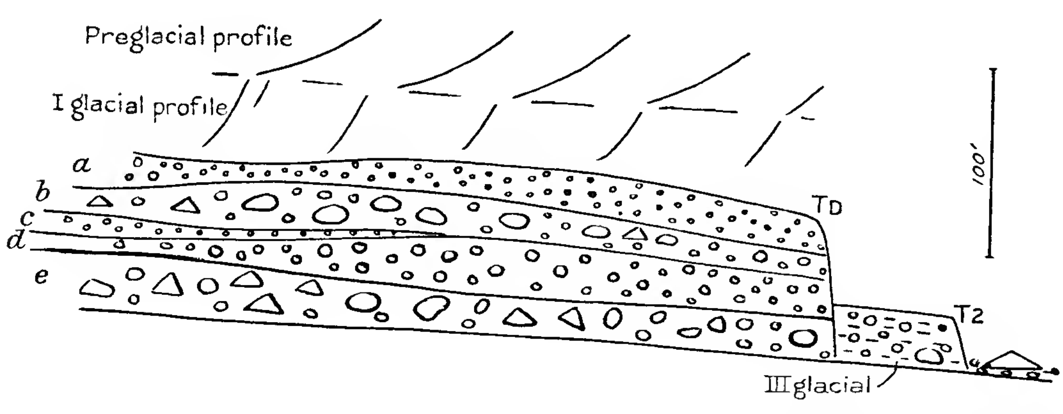


FIGURE 51.—Diagrammatic section of sequence at Nunawan. *a*, Late second outwash; *b*, second glacial ground moraine, second (Lioru) advance; *c*, fine outwash of second glaciation, first (Pahlgam) advance; *d*, coarse outwash of second glaciation, first advance; *e*, first glacial ground moraine.

Early first interglacial.—The first glacial cemented conglomerate is overlain disconformably (fig. 47) by over 60 feet of fine laminated cream-colored shell-bearing silt, carrying a few sand layers with clay partings and fragments of indeterminate bone. There is no passage upward from the conglomerate to the silt, which is a late deposit like that of first interglacial age in the Sind–Lower Karewa clays. It can be traced through Krungus upward to Kanjdori, beyond which it does not appear. It thins out upstream and its relationships are altogether very closely similar to those of the Lower Karewas of the Sind.

Late first interglacial.—Separated from the silt by a disconformity is a series of some 40 feet of coarse green current-bedded sands, yellow earthy claylike material, laminated yellow-green sandy silt, and a very conspicuous layer of hard, cemented current-bedded sandstone as much as 4 feet in thickness, with coarse subangular grains as large as a quarter of an inch, gravel as large as half an inch and locally 2 to 3 inches. Because of its resistance to denudation this material projects from the face of the Islamabad-Bawan terrace, and the water of side streams cascades over it. It forms boulders in the third glacial deposits and, in general, separates the laminated silt below from the earthy clays above.

All of this deposit can be traced, like the earlier, as far as the Kanjdori region (figs. 43–47). At Islamabad, on the hillside above the telegraph office, this bed is seen to abut against the hillside, where a band of poorly preserved fish bones and shells can be found (fig. 43, *a*). Here too the green sands become beach sands mixed with pebbles of the local limestone and associated with a cemented breccia, which can be followed up the hill. A scree fan plunging into the lake can be visualized. A similar scree is to be seen at Bawan (fig. 45). The lower disconformity and the change in lithologic facies point to a lowering of the Lower Karewa lake level when fluviatile action became more pronounced.

The relationships of the late first interglacial material are obscure, but much light is thrown on the question by the section in figure 46. Below this region the green earthy silts are overlain immediately by brown granular clay, but because of their comparable softness the character of the junction is not always obvious, though a disconformity is indicated at least. In the region of Kanjdori, however, the brown clay, besides overlying the green silts, overlies a massive loose boulder conglomerate which is of later age than the Ganeshpur moraine, being related to the Lioru moraine. This conglomerate, in turn, is banked against a surface eroded out of the first interglacial silts; hence the junction in the lower reaches, between green silts and brown clay, is really an unconformity. This relationship means that the Lower Karewa lake was still further lowered after deposition of the green silt, so that it was already partly eroded when the ice advanced a second time—conditions comparable to those prevailing in the Sind Valley.

Second glacial.—The loose massive conglomerate mentioned in the preceding paragraph can be traced continuously (figs. 48, 49, and 50) up to Lioru, where it is seen to overlap and envelop the large moraine of that place. It is banked against the eroded Ganeshpur moraine and overlies the ground moraine of the Ganeshpur Glacier (fig. 48). It may be 150 feet thick in places between Ganeshpur

and Lioru, where it also overlies (fig. 48, *b*) a conglomerate of finer type that belongs to an earlier phase of the second glaciation.

There were two phases of the second glaciation. There was an initial advance as far as Pahlgam (fig. 52), where the moraine was deposited, at 7,100 feet, on ground moraine of the first glaciation and at the junction of the West and East Liddar rivers.[1] From this point extends coarse outwash which, at Nunawan, 4

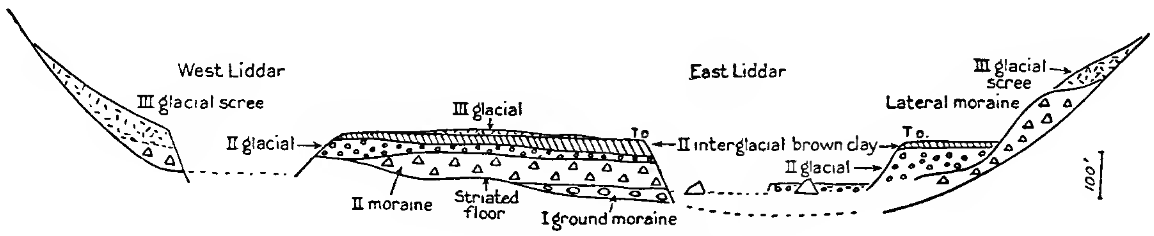


FIGURE 52.—Transverse section across Pahlgam Valley.

miles upstream from Lioru, also overlies first glacial ground moraine (fig. 51). Finer conglomerate succeeds this, showing that the ice had retreated from Pahlgam, though not necessarily very far. This finer material can be traced still farther downstream, where it underlies, at milepost 21, the Lioru moraine (fig. 50) and still lower can be seen at Batakut (fig. 48, *b*), covered by outwash of the Lioru stage.

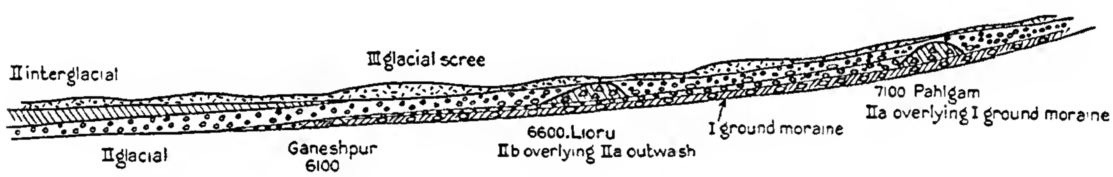


FIGURE 53.—Diagrammatic longitudinal section, Pahlgam to Aish Makam.

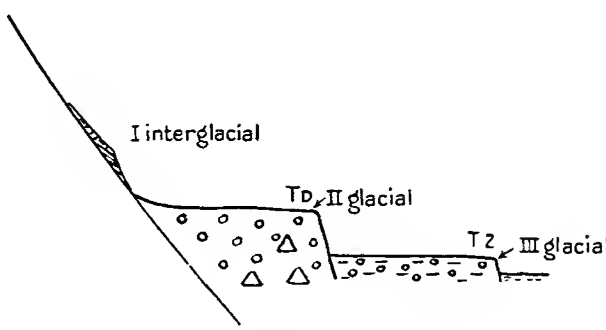


FIGURE 54.—Section on the right bank of the Liddar at Rainspal.

The Pahlgam moraine is over 50 feet thick[2], rests partly on a glaciated floor and the first ground moraine, and has a lateral moraine which appears above the church.[3] Just upstream, at the village itself, a belt of large erratics marks a moraine limit, perhaps a retreat stage.

[1] Grinlinton, 1928, pl. 31.
[2] Ibid., p. 342.
[3] Ibid., cf. pls. 31 and 37, G.

At Nunawan (fig. 51) the finer Pahlgam outwash is overlain by ground moraine which can be followed to the Lioru moraine at 6,600 feet (fig. 50). This moraine is over three-quarters of a mile in width, with the usual inner steepness and the tailing off downstream. It is almost 150 feet thick, which suggests a thickness of ice of at least that amount. The associated outwash envelops it and forms the main mass of the highest terrace in the upper parts of the lower Liddar (fig. 49). It covers the Pahlgam moraine (fig. 52), and its outwash still forms the highest terrace at Rainspal (fig. 54), below the third moraine.

The general relations of the various members of these second glacial and intraglacial phases are indicated in figure 53.

Early second interglacial.—Here, as in the Sind Valley, the early second interglacial material consists of a great thickness of brown granular clay without bedding and only partial banding, formed during the second damming of the Kashmir Basin in Upper Karewa time. It must have been over 500 feet thick,

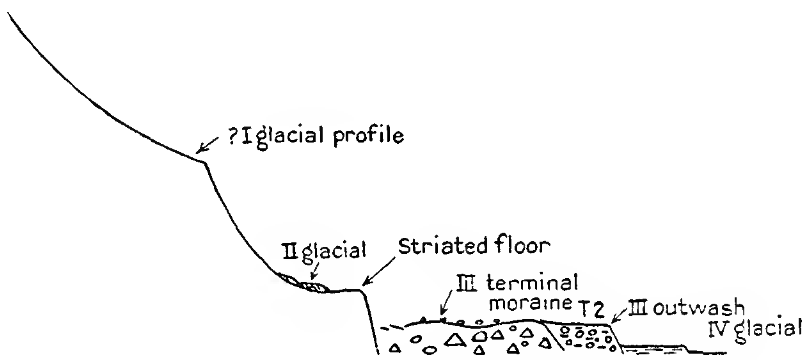


FIGURE 55.—Composite section at Nekabatun, shoulder and moraine. (See Grinlinton, 1928, pl. 37, F.)

for it almost enveloped the hill behind Islamabad before erosion removed so much of it (fig. 43, *a*). It is very well developed up as far as Kanjdori (fig. 47). It is last seen, thinning out, below Ganeshpur (figs. 48, *a*, and 53).

At Pahlgam (fig. 52) a brown clay overlies the Pahlgam moraine, and it is with difficulty differentiated at the junction.[1] This clay seems to be of second glacial age, or very early second interglacial.

Late second interglacial.—After deposition of the brown clay the water level dropped and extensive erosion took place, forming terrace T1, which, between Bawan and Islamabad, is almost 300 feet high (pl. VIII, 2). This well-developed erosion surface has been produced by erosion of the Jhelum, as the surface is continuous far beyond the limits of action of the Liddar. The Liddar, however, because it had a greater gradient, was able to transport, and the remains of its old aggraded river bed can be seen at Bawan on the left bank (fig. 45), where brown-yellow redeposited brown clay, with bands of angular limestone blocks, passes down into redeposited brown clay, with much angular limestone, but less bedded.

[1] Grinlinton, 1928, cf. p. 338.

Redeposited clay with boulders is well seen at the level of Kanjdori (fig. 46), where it forms T1, filling the erosion channel that cut the brown clay. Farther upstream (figs. 49–52 and 54), the deposition surface of brown clay does not exist, so that TD (the surface of second glacial conglomerate) coincides with T1; or else T2, of third glacial age, is mixed up with T1 in that its conglomerates cannot be distinguished, the third glacial outwash waters having absorbed preceding deposits with their own effluent material. Still higher the erosion of T1 is represented by truncation of the second glacial floor (fig. 55). This erosion, as in the Sind, was associated with uplift, and near Nekabatun it has been possible to observe tectonic phenomena similar to those found near Hari (figs. 29 and 30).

Upper Liddar

The third glacial and later stages all have their moraines within the limits of the upper Liddar. Beyond Pahlgam the valley floor begins to rise steeply at Nekabatun, through the steep gorge of Phraslun to the huge step of the Piush Gorge.

Third glacial.—In the upper Liddar the third glaciation is represented by solifluxion scree of a nature similar to that in the Sind, capping the high terrace. Terrace 2, of third glacial age, is generally low and couched at the base of the huge erosion escarpment of the second interglacial period and is composed of redeposited brown clay with many beds of boulders (figs. 43, *b*, 46, and 51). It merges with the third glacial moraines.

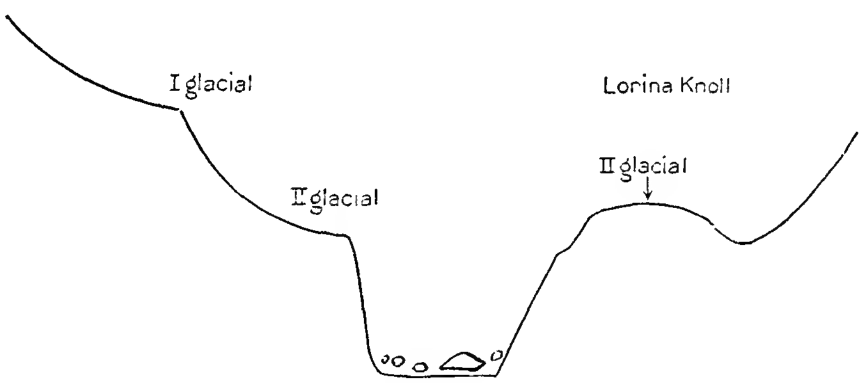


FIGURE 56.—Composite section, Phraslun Gorge and moraine. (See Grinlinton, 1928, pl. 32.)

The third glaciation had four advances to, or at least four stages of moraine formation at, places between Nekabatun and Tanin. First at Nekabatun[1] (fig. 55) a moraine extends for three-quarters of a mile at 7,500 feet against an erosion surface truncating a glacial trough of second age (pl. IX, 2). At Phraslun, at 8,100 feet, moraine material lies immediately below the gorge, again in a gully cut in second interglacial time (fig. 56), through the roche moutonnée of the Lorina Knoll[2] of second glacial time. Above lies another floor of first glacial age. Then

[1] Grinlinton, 1928, p. 329.
[2] Ibid, cf. pl. 32.

at the point marked by the two D's in "East Liddar" of map 43 N/8, between Phraslun and Tanin, appears a moraine belt at 8,900 feet, with another just below Tanin at 9,100 feet. The outwash from this series forms a well-developed terrace. The quadrifold division is strongly akin to that of the Sind third glacial cycle.

The next series of moraines, probably belonging to the fourth glaciation, lies above the Piush Gorge at Burzulkut and the outlet of Shishram Nag. These moraines have a topography as immature as that of the moraines of the Sonamarg Basin or even the fifth advance of the Sind. There is no conclusive evidence, as in the Sind, for a separation of the fourth and fifth stages, but the reader is referred to Grinlinton's work for the detail, which will not be repeated here, except for the section of Piush Gorge[1] (fig. 57), which it seems showed a well-developed

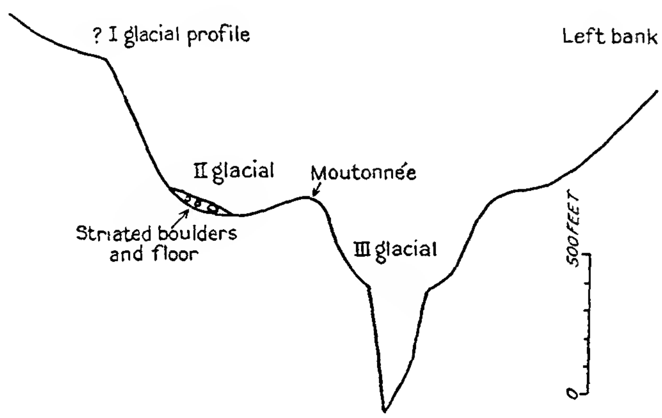


FIGURE 57.—Section of Piush Gorge.

second trough within a first profile, and a third trough cut out of the second, with a subsequent gorge cutting of late date. Plate X, 1, shows a striated boulder lying in conglomerate in the second glacial trough.

Grinlinton's subdivision into high-level and low-level epochs of glaciation has been mentioned. He points out[2] U-shaped troughs at 13,000 feet and the zone of fall away from that height. The present Liddar Valley was formed when the step was cut. This step is similar to the preglacial notching of the valley profiles seen in the Sind. The glaciation of the high level could well have occurred during the early phase of glaciation, before the intense erosion during the first and second interglacial periods. Much detritus had already been formed[3] before the low-level epoch—that is, before the Pahlgam stage of erosion—and therefore it suggests that the formation of the high-level trough was initiated during first glacial time. Grinlinton continues: "In view of the fact that in certain places the upper lip of the step can be traced under the present snow fields and névé it is fairly certain that, except very locally and unusually, the High-Level Epoch ice did not follow down, sagging into, the regional step as it was formed," supporting the hypothesis that the

[1] Grinlinton, 1928, cf., pls. 23 and 38, E, pp. 309–315.
[2] Ibid, p. 308.
[3] Ibid, p. 353.

step was cut during a time when the ice was confined to the higher parts of the range. This hypothesis, of course, assumes that there was no glaciation in "preglacial" time, before the advance of the first big glacier, an assumption which may be wrong, because the Himalaya was probably high enough even in Pliocene time to bear ice.[1] But the Sind Valley features older than first glacial time show no sign of glaciation whatsoever.

Except in these high reaches the Liddar Valley was deeply eroded when the first ice advanced to Ganeshpur. The confluence of the East Liddar and West Liddar glaciers helped to push the front farther down than it would ordinarily have reached if the ice had been supplied by one valley only. This is a point to be considered when comparing the extension of the third ice, which was confined to the upper Sind.

It has been seen that Grinlinton's first or Pahlgam stage of the low-level epoch belongs to the second glaciation. The next stage—the Chanahan or Nekabatun—is represented at its greatest extension by the Nekabatun Glacier, which lies against a slope cut into the second glacial trough.[2] The great recession that filled the cup of Shishram Nag [3] is represented in the Sind Valley by the basal horizontal cemented conglomerate of the Sonamarg Basin. The next advance in Grinlinton's scheme is the Mainpal, when moraines were deposited below Shishram Nag near Burzulkut, above the Piush Gorge. In comparing this advance with the Sonamarg stage of the Sind glaciation it must be borne in mind that the West Liddar is much smaller and therefore the late stages are but poorly represented and only at high altitude. The post-Mainpal recession was slow and irregular, marked by a pause and a pulsation (the Tuliyan Huts stage), which may be correlated with the retreat stage of the fourth Sind ice at Vichmargi. The Dudal Huts stage would then be the fifth glaciation followed by a period of recession, just as in the Sind.

SUMMARY

The foregoing observations in the Sind and Liddar valleys indicate that the Quaternary glaciation of the inner Himalaya in this region may be divided into a main series of four glacial and three interglacial epochs, of which the first two glaciations were more intensive than the later two, with still later oscillations or stages of retreat. Each glacial period saw intraglacial pulsations of the ice front, now more evident in the late stages than in the early, because of erosion and weathering. Even so, it has been found possible to recognize at least two advances during second glacial time, four advances and a retreat halt in the third period, and four advances in the fourth period, with several retreat stages. An oscillation of climate during second interglacial time has been recognized.

All these points are graphically recorded in figure 58, which indicates the approximate relative duration of the glacial and interglacial periods and the relative intensities of glaciation as measured by the extension of the glacier fronts.

[1] On the other hand the climate was warmer and in late Pliocene time probably rather dry.—De Terra.

[2] Grinlinton, 1928, p. 357.

[3] Ibid., p. 380.

This extension is no absolute criterion for intensity of glaciation, but Penck and Brückner have shown that the variation of the snow line bears a linear relation to glacier extension; hence the latter can be utilized for purposes of comparison.

There are other variables to be taken into account. Uplift of the main range itself increased the gradient of the thalweg and the intensity of glaciation of later stages, but was counteracted by erosion during interglacial periods. Moreover, the Pir Panjal was also rising and blanketed off a great part of the southwest monsoon, hence decreasing the amount of precipitation on the main range. It is impossible to make a calculation of the effects of these variant factors, but, in result, such calculations, if possible, would make the second glaciation bigger than the first, and the third glaciation approach the first in intensity; for the effects of uplift of the Pir Panjal during the first interglacial period would more than offset the increase

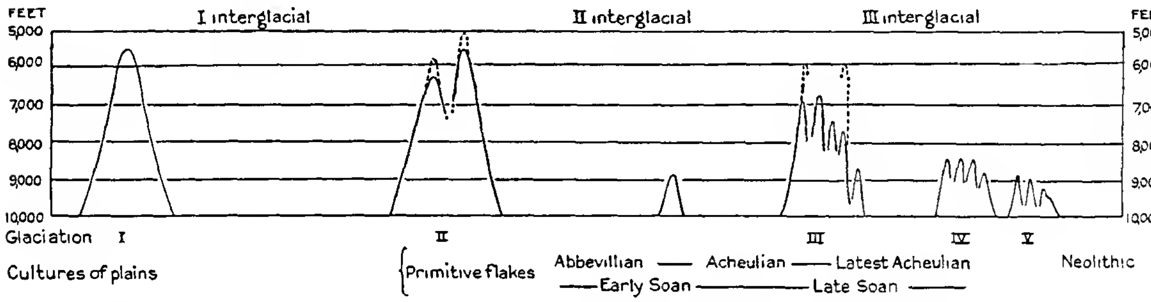


FIGURE 58.—Diagram to illustrate relative duration of glacial and interglacial periods, with approximate relative intensity of glaciation as indicated by the respective limits of glacier advance (Himalayan slope).

of gradient in the inner Himalaya, an increase which was further reduced by late first interglacial erosion; and the blanketing effect of the great uplift of the Pir Panjal during the second glacial and interglacial periods, combined with the long-continued and intensive erosion of the second interglacial phase, makes it highly probable that the third glacier would have advanced farther. The dotted lines of figure 58 show a possible relative extension if these factors had not been in operation.

The duration of the glacial periods is difficult to determine. If the size of moraines is at all a criterion of duration, then the second glaciation was longer than the first, which was longer than the third, and this in turn was longer than the fourth. The amount of deposition varied; that from the first two glaciations was much greater than that from the later ones. The first deposition was greater than the second in lateral extent, but the second glacier was floating and could not expand its detritus far, except as glacial clay, and this, if the brown clay of the early second interglacial period is assumed to be essentially of glacial origin, was much greater in quantity than in the first glacial period.

Compared with the interglacial periods the glacial periods were much shorter. The interglacial erosion of terraces was much greater than that during the glacial periods. The interglacial deposits are fine, requiring lengthy periods for deposition, yet they are almost as thick as the coarse glacial deposits. There is more evidence to show the comparative duration of the interglacial periods.

The deposition surface of early second interglacial time is high above the other terraces and is very much weathered and eroded. Its deposition was followed by a long period of erosion during which the climate became damper. The second surface thus produced is also well worn and eroded, whereas the lower terraces are very much less eroded.

If the amount of erosion during these various phases is compared and allowance made for uplift and its consequent effects, it seems that the whole of the time from the third glaciation onward has been much less than a third of the preceding phases together and less than the second interglacial period itself. The first interglacial period, too, was longer if the amount of deposition is considered a criterion. But the first interglacial erosion was less than the second interglacial erosion. At the same time it should be noted that boulders of a particular biotite gneiss, though they appear fairly fresh in the conglomerate of the third stage, are much corroded in the outwash of the second stage. The second interglacial fan breccia of Sonamarg is another deposit which required much time for formation.

The moraine topography of the fifth stage is not much different from that of the fourth glaciation but very much younger than that of the second and third stages; the fourth and fifth are therefore closely bound up with one another.

On these grounds the relative duration of the interglacial periods was in the ratio 4: 5: 4 for the first, second, and third, and all later stages are represented in figure 58.

C. THE PLEISTOCENE RECORD IN THE KASHMIR BASIN

SECTIONS IN THE KAREWA SERIES

General Mode of Distribution of Ancient Valley Fill

From the foot of the Kishenganga watershed to the southeast corner beyond Islamabad, the floor of the Kashmir Valley is built of little-consolidated lake beds and younger alluvial soils (pl. LV). The greatest portion of this area, which is over 2,000 square miles, exhibits yellow and gray silts and sands, underlain by boulder gravels and lake clays, into which the Jhelum and its tributaries have carved a relief of varying character. On the right bank of the river these beds form flat tablelands and terraces, which rise 450 feet above the Jhelum level, as between Avantipur and Bijbiara (pl. II, 3). Northwestward their preservation is less complete, and between Srinagar and the Wular Lake only terrace remnants and hillocks testify to the regional formation of these deposits. At Handawor they fill the entire breadth of the valley and, as the underlying rock floor here has an undulating relief, it rarely came to the formation of tablelands, the Pleistocene beds covering hillocks and ridges like a mantle. The same situation is found on the edge of the Pir Panjal slope. There ancient divides and spurs emerge from the Pleistocene beds, and the wide level surfaces, the "karewa"[1] proper, display effects of diastrophism which led to dissection and local tilting of levels. Where tributary streams debouch, the

[1] It should be noted that the term "karewa" is used descriptively by the Kashmiris, while Middlemiss and others introduced it as a stratigraphic term.

silt and clay deposits have been replaced by gravelly deltas, and as the rivers are braided these deltas in many places merge to form a wide gravel plain. Such is the case near Islamabad, where the Liddar, Bring, Sandran, and Jhelum rivers make a semicircular group of streams and rivulets which have removed most of the original valley fill (pl. LV).

This mode of distribution reveals that the most complete geologic sequences can be expected in the area where the "karewa" flats are well preserved, such as between Pampur and Bijbiara and also on the left bank of the Jhelum between Badgom and southeast of Pulawom. Naturally, interest must be focused first on those places where the chronologic record is most perfect, as at Sombur, where the Pleistocene beds rest on bedrock.

Sombur Quarry Exposures

About 12 miles southeast of Srinagar the Jhelum swings conspicuously around a limestone promontory which projects toward the center of the valley from the

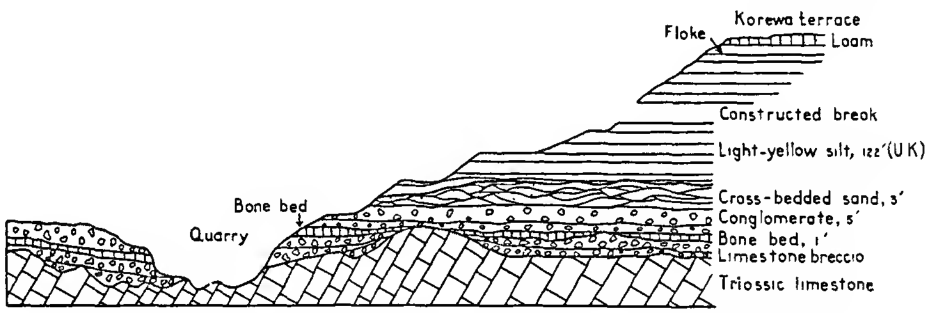


Figure 59.—Section through Sombur quarry at locality 1. U.K., Upper Karewa beds.

mountain flank near Barus. From its southeast-northwest course the river here is deflected northeastward and has exposed a ledge of Triassic rock overlain by Pleistocene beds (pl. X, 2 and 3). At Sombur the villagers have quarried this rock for road building, and the artificial exposure permits a unique insight into the nature of the overlying beds.

As figure 59 shows, the limestone displays an irregular yet, on the whole, flat surface on which rests a breccia made up of angular limestone débris. In the upper portion of the quarry the limestone is weathered and broken up into a mass of brecciated rock which almost grades into the overlying breccia. The latter is thickest at places where the limestone is pitted and where it bears a "karst relief." This basal breccia is overlain by a conglomerate layer in which the components, mainly Triassic limestone and trap, are water-worn. Lenses of fine sand and clay appear locally, but one thin yet distinct clay bed, 8 inches to 1 foot thick, appears to be constant, as it recurs both at localities 1 and 2 (figs. 59, 61) and at the outlet of the Liddar Valley near Islamabad (fig. 47). On account of its content of fish, bird, and mammal bones it is called "bone bed," and, as it is the only layer in the entire Kashmir Pleistocene that contains an abundance of fossil bones, it is worth fuller description.

The bone bed at Sombur is a light-gray to yellowish clay in which fresh-water shells, fish vertebrae and bones, lacerated plant fragments (*Equisetum*-like forms), broken limb bones of artiodactyl mammals, and elephant remains occur. The fish bones form clusters, although vertebrae are found singly throughout the clay. The clay is speckled with a white mineral which, upon microscopic and chemical study, was specified as a magnesium-bearing variety of collophane, a hydrated ferrous calcium phosphate. As it was found that a fragmentary incisor of a small fossil mammal had been metamorphosed into this substance, it is safe to assume that most of these white specks of minerals are derived from tooth fragments. Thorough searching for complete tooth or skull remains was not successful, but, on the first day of my examination of the site, I found a well-preserved tusk of *Elephas*. Repeated excavations were rewarded in 1935 by the find of additional skeletal parts of the same animal and of an immature specimen represented by a small molar. This specimen had previously been identified as *Elephas* aff. *namadicus*, but with the new material it can be ascribed to a more primitive type, *Elephas* cf. *hysudricus*.[1] This form belongs with *E. planifrons* to the oldest of the Pleistocene Indian elephants, which appear to be restricted to the older Upper Siwaliks (Tatrot-Pinjor zones) of northern India.[2] As has been pointed out elsewhere,[3] the older Upper Siwaliks represent, in our opinion, the lower Pleistocene in the Himalayan foothills, which at many places is disconformably overlain by coarse boulder conglomerates containing glacially shaped boulders that indicate the extension of the second Himalayan ice advance. In this light the Sombur section, particularly the bone bed, becomes very significant and we ask ourselves what its origin was and whether the underlying and overlying beds are of glacial age. The curious mixture of shells with bones of mammals, fish, and birds in a thin clay bed of this kind obviously signifies a shore deposit of a lake. The absence of silt and sand and the abundance of delicate fish vertebrae and isolated mammal remains and teeth indicate deposition in quiet water. Off-shore currents and wave action were presumably sufficiently powerful to lacerate the stranded or bogged bodies of land and water animals, which were probably preyed on by large birds. Hora (1937), to whom the fossil fish remains were entrusted for study, states that they belong to the Schizothoracinae, now living in Kashmir as lake or sluggish-water forms.

The bone bed, then, represents the same first interglacial shore deposit as was described by Paterson from the lower Liddar Valley (see p. 73). It belongs to a greatly compressed stratigraphic sequence, and therefore its thinness does not necessarily indicate a brief period of lacustrine conditions.

The conglomerate above the bone bed shows well-assorted constituents such as limestone, trap, and quartzite with a few subangular boulders as much as 1 foot in diameter. The pebbles are worn to a degree, as might be expected from components washed out of a delta or fan. This, indeed, must have been the origin of

[1] Dr. Colbert, of the American Museum of Natural History, endorsed this determination but stated that the specimen cannot be definitely assigned to this form until its skull has been found.

[2] See Colbert, 1935.

[3] De Terra and Teilhard, 1936.

the conglomerate, for it reappears along the mountain side near Krew, some 4 miles northeast of Sombur. Here a typical fan formation is exposed, emerging from underneath the yellow lake beds and resting against traprock (fig. 60).

As fluvial fans of this size are not forming now, we may conclude that their formation dates back to a time of intense transportation and accumulation of rock débris. For reasons given below, I am inclined to interpret this conglomerate as a fluvial deposit of the late first interglacial period, when the lake had become shallower.

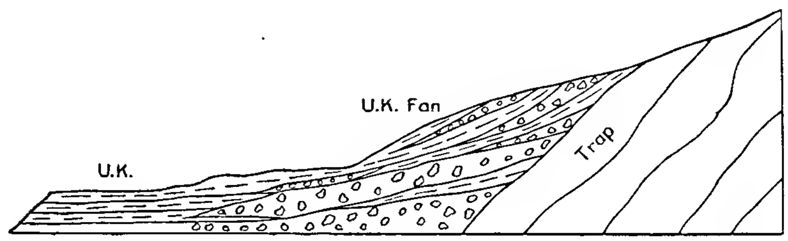


FIGURE 60.—Cross section through fan and scree formation near Krew. U.K., Upper Karewa beds.

The cross-bedded sand on top marks a zone which is widely distributed over the entire northeastern valley (fig. 47). It is usually of greenish color due to amphibole, augite, and chlorite minerals, which are derived from the Panjal trap rock. In this section it is gray, but at locality 2 of Sombur it displays the typical coloring and cross-bedding. At locality 1 its association with the conglomerate is evident, because the bone bed below and the lake silt on top apparently belong to distinctly different geologic cycles. This, however, is precisely the type of stratigraphic record which characterizes the earlier Pleistocene sequences at the outlets of the Sind and Liddar valleys. The resemblance is indeed so striking

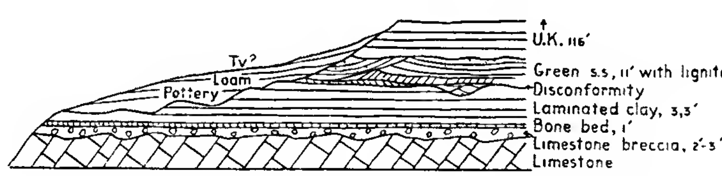


FIGURE 61.—Section in Sombur quarry at locality 2. U.K., Upper Karewa beds.

that one cannot help but recognize in the Sombur sections the record of the first lake period (Lower Karewa lake beds) separated from a later lacustrine stage (Upper Karewa) by a fluvial stage of first interglacial time and a hiatus. Sombur even furnishes the paleontologic proof for what otherwise would have to rest on pure geologic evidence, for it bears the record of an early Pleistocene elephant in the Lower Karewa beds. In addition, locality 2 (fig. 61) serves to supplement our knowledge gained from the first section. Not only do we find here a laminated lake clay, between the bone bed and the green sand, indicating a more continuous littoral record of Lower Karewa time, but evidence of a period of erosion antedating the fluvial episode, as suggested by the disconformity.

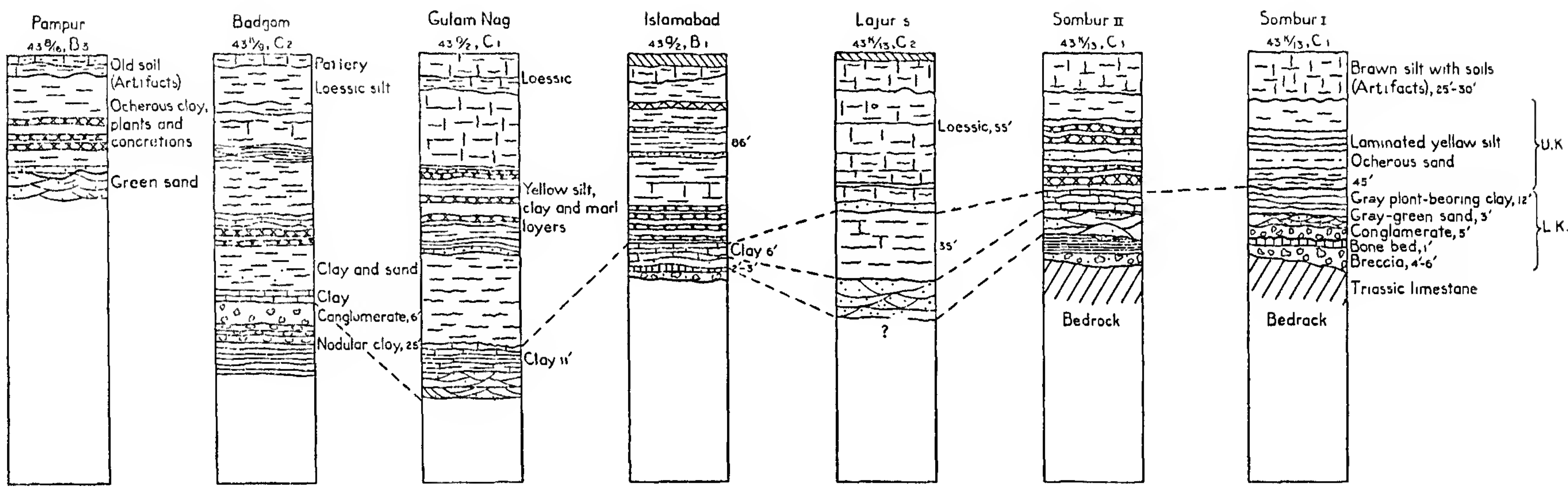


FIGURE 62.—Karewa sections southeast of Srinagar. Dashed line marks boundary between Upper Karewa (second glacial–second interglacial) and Lower Karewa (first interglacial) beds. Numbers below locality names are those of topographic sheets and their single sections.

The bone bed at locality 2 yielded broken bones of birds, fresh-water snails, and fish vertebrae. The sand layer is disconformably overlain by a thick series of light-yellow silts, clays, and fine sand. These beds not only build the even surfaces right off the Jhelum stream but they invade the larger valleys, where they overlie the terminal moraines or respective outwash deposits of the second glaciation. Topographically and geologically they therefore deserve detailed description.

Upper Karewa Beds along Jhelum River Southeast of Srinagar

From Sombur to the mountain slope near Barus well-stratified silt and clay form an even land surface 4 miles wide and 95 to 110 feet above the Jhelum level. This is part of a widely extended land form whose conspicuous flatness at first gives the impression that it is a valley floor dissected by the Jhelum and its tributaries. Farther upstream this elevated level is again encountered on the left bank, where it forms the "karewa" of Junzpur. On the right side it is well preserved near Bijbiara, and east of Islamabad the deltas of the Arpat and Liddar streams have dissected this tableland, and the left tributaries, such as the Rimbiara and Vishav, have removed most of it.

Figure 62 gives the sequences from scattered exposures, all of which lie southeast of Srinagar. The green sand and the conglomerate at Badgom are found at the bottom of the laminated clay and silt series. This relation permits correlation with the Sombur sections, especially as the bone bed and the basal breccia also appear wherever the lake beds touch the rock floor. The conglomerate layer at Badgom signifies the presence of a fan deposit, which, as demonstrated on page 168, is the outward fringe of a fluvioglacial lacustrine delta of the second Pir Panjal glaciation. Without exception, clay appears as a basal layer of the Upper Karewa silt. The clay is commonly gray, much of it ocherous, with limonitic concretions and usually rich in fresh-water shells and plant remains. The plant remains consist of lacerated stems of rushes and grass, and in many places the clay carries a certain amount of pollen.[1] None of the plant fragments collected admit of any generic determination. However, it is significant that no tree leaves occur in this clay, in contrast to the wealth of leaf impressions found in the Lower Karewa clays of the Pir Panjal side. This feature and the predominance of grass and rushes, in combination with the wealth of fresh-water invertebrates, speak for lacustrine deposition in a shallow lake.[2]

Much more difficult to analyze is the overlying series of stratified yellow silt and sand which form the bulk of the Upper Karewa beds. Generally these deposits are divided into a lower group of laminated or well-bedded silts with alternating layers of marl and fine concretionary sands, and an upper silt of loessic character. The ratio of sand to silt or clay to silt varies greatly from place to place, at least in the sequences along the northeastern valley slope. In the neighborhood of Badgom and Kulgam—that is, in the more centrally situated exposures—I noticed a rapid

[1] See Wodehouse and De Terra, 1935.

[2] Near Pampur the beds at this horizon yielded *Pisidium hydaspicola* Theobald, *Valvata piscinalis* (O. F. M.), *Planorbis planorbis* var. *tangitarensis* Germ., and *Gyraulus* cf. *pankongensis* (Neville) v. Mart. These specimens were determined by Dr. Prashad of the Indian Museum in Calcutta.

decrease in limy concretions or marl layers as compared with the regular presence of marl to the right of the Jhelum. The marl is as much as 2 inches thick but is commonly thinner and usually impregnated with ferrous and manganese oxides. Good exposures are found on the main road south of Pampur and in the gullies northeast of Bijbiara. The increase of calcareous matter from the center of the valley to the lateral regions indicates a primary change of facies, due, no doubt, to the higher lime content of the lake water and to concentration of lime by organic compounds in littoral waters. For not only was there greater abundance of vegetable matter, but the inwash from the limestone-bearing Himalayan Mountains here made for higher concentration of lime in off-shore waters. Dr. Krynine in his report on the Pleistocene sediments (see p. 235) states that the Upper Karewa marl is a chemical deposit in seasonal lacustrine environment together with wind-blown stuff. Its content of "red bed" detritus suggests eolian drift from the Siwalik beds. At present the carbonate concentrate in the Kashmir lakes is small, as Lundquist (1936) indicates. It is largest in Lake Manasbal, which receives especially large quantities of lime from the Paleozoic and Triassic limestones. The question arises whether these marl-bearing beds can shed any light on the climatic conditions of Upper Karewa time. So far as their fossil record is concerned the rarity of fresh-water shells in the marl as well as in the corresponding layers in the central portions of the valley seems indicative of unfavorable conditions for invertebrate life as compared with the previous period of clay deposition. But is this scarcity of shells not perhaps due to unfavorable preservation of fossil records? If shells had originally been embedded in the littoral sediments they might subsequently, of course, have been dissolved during accumulation of humus (under swamp conditions). In that event, however, one would expect to find abundant shells in the homotaxial layers of the centrally located sequences. Their absence seems to indicate that the postclay and preloessic period of sedimentation made, in fact, an unfavorable habitat for these organisms. The concentration of carbonate of lime was definitely greater in this period than at any previous or succeeding time. The lake may then have been saturated with carbonates or algae of lime, especially in the northeastern shore regions. As the marl layers interchange with silt or shell-bearing clay, this condition cannot have lasted long. A period of lime deposition thus was interrupted several times by the accumulation of colloidal and detrital matter. This conspicuous record can best be explained by changes in lake level. After a period of normal fresh-water composition, during which plant- and shell-bearing clays were laid down, the lake level fell and the lime content of the water rose. Marl and concretionary clays were deposited. A return of higher water level brought about dilution and deposition of silt or clay. The presence of five to eight marl layers speaks for a period of wide fluctuations of the water table. These could have had either a climatic or an erosional cause. Decision on this alternative can obviously not be reached unless the full sedimentary and morphologic records from this period have been deciphered. Evidently it was a time with a geologic setting different from either the previous or succeeding periods. To realize this difference we must turn to the overlying group of deposits.

The bulk of the Upper Karewa beds consists, in these sections, of a group of fine yellow or bright-gray silt with gray or ocherous layers of fine sand. The thickness in the different sections ranges from 55 to almost 200 feet. The top layers are made of a brown silty clay with granular structure, separated from the silt by an erosional disconformity. For reasons discussed elsewhere this uppermost layer cannot belong to the Upper Karewas and will therefore be discussed in the section dealing with later periods in Kashmir. Casual observation might easily lead one to suspect a loess in this silt formation, for not only are the coloring and composition loessic but at places the formation seems to lack any structure. Such exposures, however, are rare, and more commonly the silt is stratified and at places even laminated. Bedding planes are well developed and very regular. Lateral changes from a pure silty to a sandy facies were observed more commonly in the exposures right off the Jhelum River. The sand layers are in many places stained throughout by ferrous oxide, and at Badgom, near the junction of the Dudhganga and Shaliganga rivers, they contain vertebrate remains (*Cervus* sp.) and freshwater shells. Rather commonly the silt layers are cemented to form a mud or siltstone, and it is in these strata that indistinct plant remains may be found, mainly grasses and ocherous impressions of rushes. Of grasses, *Poa* is represented by pollen grains (Wodehouse and De Terra, 1935). *Ephedra*, which is abundantly found in Upper Karewa silts, now grows prolifically in Kashmir at dry places, and its presence in these silts might well indicate dry climatic conditions for that period.

The lithologic and faunistic aspects of this silt group undoubtedly point to lacustrine origin, but it should be kept in mind that fluvial inwash and eolian drift presumably provided for changes in sedimentation. Facies differences connected with fluvial inwash from the mountains are discussed in the following section. Attention must here, however, be drawn to the origin of the yellow silt and siltstone layers. It is noteworthy that the silt attains a loessic nature mainly in the centrally located sections, as also along the outer rim of the Karewa ridges. The fineness of the silt, its uniform mineral composition, and the absence of coarse components might well be due to derivation from the finest rock flour transported by Himalayan or Pir Panjal streams toward the lake center. Local laminae could have developed by slow precipitation of silt held in suspension, but it is surprising how few laminated silts were observed. Had this material been exclusively derived from inwash, its lithologic uniformity, which is in contrast to the variability in the mineral composition of the sand layers found here and there in the silt, would be difficult to explain. There is also a strong resemblance between this silt and the loessic deposits in the adjoining northwest Punjab which, on previous occasions,[1] have been interpreted as "pluvial loess." Thus the question presents itself whether the loessic silt of the Upper Karewa group might not be partly of eolian origin. The presence of pollen grains generally proves wind action, and so does the increase in the thickness of silt toward the center and Pir Panjal flank of the valley. For this region lies on the lee side of the dust-carrying winds, which even now blow from the plains across the southern mountain rampart. It is here that the greatest

[1] See De Terra and Teilhard, 1936.

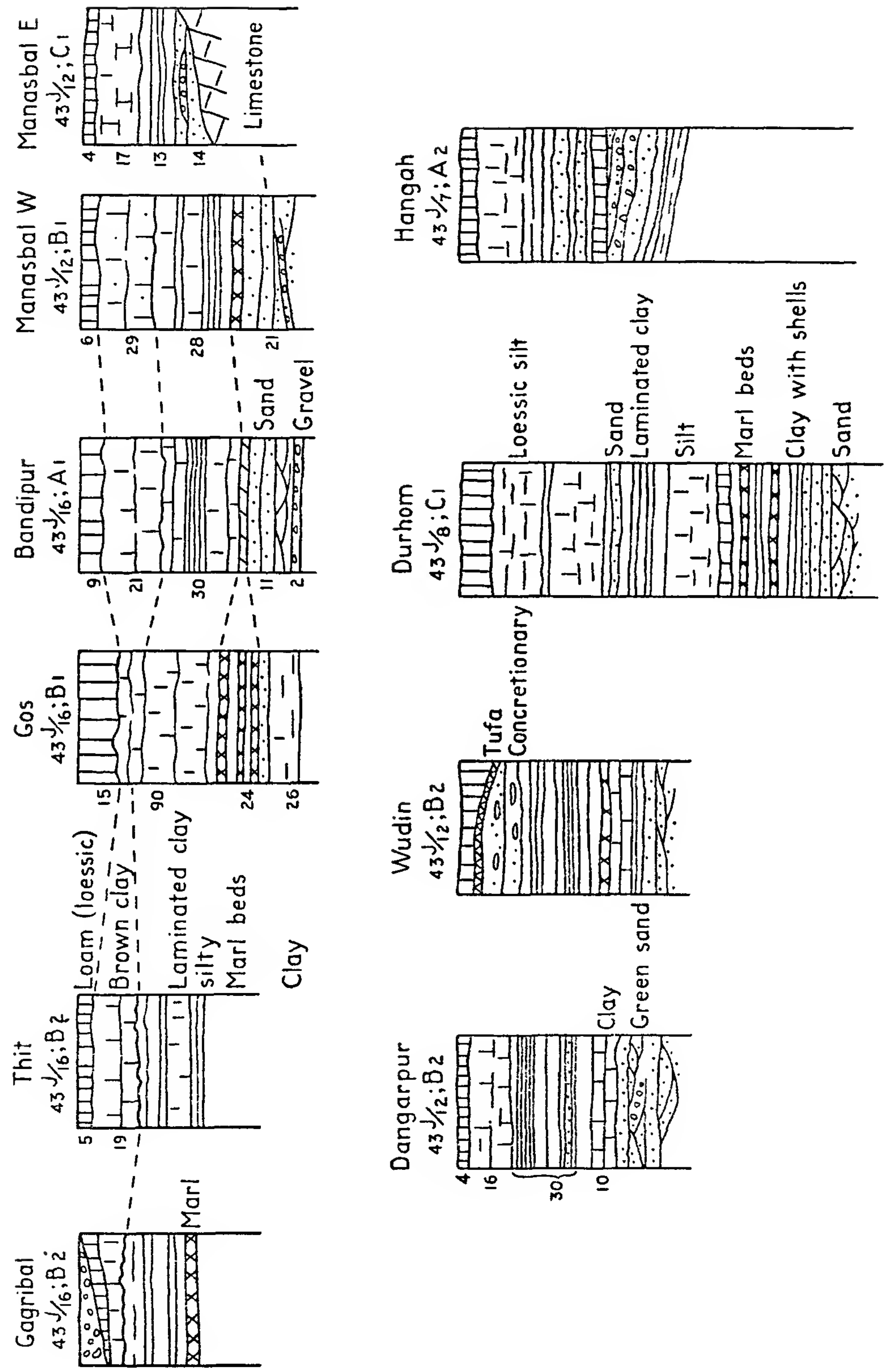


Figure 63.—Karewa sections northwest of Srinagar. Figures beside columns indicate thickness in feet. Numbers below locality names as in figure 62.

precipitation occurs during the monsoon period, and here also the terraces are coated with younger loess. As the silt beds contain records of lake life in shallow water, dust may have fallen intermittently for a long period and settled under water. Such a process would seem to account for the various features of the silt, which combines the otherwise contradictory characteristics of lacustrine, eolian, and fluvial deposition. (See Krynine's report.) Periodically this lacustro-eolian process might have been replaced by deposition of fluvial sand and silt. Such an agency would account for the local presence of vetebrate remains in the sand layers.

Upper Karewa Beds in Northwestern Portion of Valley

The Upper Karewa beds, which are still well exposed along the river at Pampur, continue northwestward toward Srinagar and Gandarbal, but they are there less well preserved. Not only has the Jhelum here eroded most of the lake beds, but a chain of lakes and marshes occupies a large area of the karewas which normally would have formed the valley floor. Loessic silt and laminated clays with marl beds are preserved at the foot of Takht-i-Suleiman, the island mountain that projects into the valley east of Srinagar. Covered by detrital fans and loessic loam of brown coloring, the lake clays appear generally in the lowest portion of the exposures. Good sections were seen at Gagribal, Thit, Gos, and Bandipur (fig. 63).

At Gagribal the beds rest against a steeply inclined rock, which accounts for the fan formation. Ocherous laminated clays appear here as well as in the road cut 200 yards north of Thit village, where they are overlain by 24 feet of grainy chocolate-colored clay and loam. The loam contains dark bands with imperfectly preserved plants. In intermediate layers of this clay were found a few freshwater shells. The dark layers are possibly due to swamp formation during intermittent low-water stages. The marl-bearing beds are well exposed at the slope of a flat surface near Gos, north of Dal Lake. A similar section at Burzahom proved of especial interest in view of the fact that a neolithic monument here was found buried under more than 11 feet of pottery-bearing loessic loam. This deposit is described in its proper place (p. 234), but it can be said here that this site dates the age of the topmost loessic loam or clay in Kashmir as postglacial. Toward the outlet of the Sind Valley, near Malshahibagh, Upper Karewa beds are seen to rest upon fluvioglacial outwash gravels of the second Sind Glacier. (See figs. 10 and 11.) Here, as elsewhere along the Himalayan slope, Upper Karewa beds are submerged under coarse scree and at places dissected by large fans.

At Bandipur (fig. 63), a small village at the northeast corner of Ankar Lake, the valley floor rises 15 feet above the lake level. Here brown and laminated clays are underlain by a thin marl bed and gravelly sand. The sand is gray and differs in composition from the greenish sand near Sombur by carrying pebbles of quartzite and limestone. As limestone is prominently represented in the boulder gravel of the Sind Valley tract, with which this sand has also a loose consistency in common, it is suggested that the sand represents outwash from the time of the second ice retreat of the Sind Glacier. Gravels also underlie the lake clays opposite

the Sind Valley outlet at Rampur, and here the coarse boulders, of loose consistency and brown coloring, clearly indicate the outwash gravel of the second Sind Glacier.

On the road from Gandarbal toward Manasbal Lake the fluvioglacial fan reappears just above the village of Barus, under 28 feet of yellow silt and brown loam. About 1½ miles distant from Barus, at Patarmul, greenish sand and gravel are seen resting against the mountain slope. (See fig. 63, Manasbal E.) At one locality cross-bedded gravel is underlain by light-gray clay and silt, which resemble the Lower Karewa clay of the Sombur section. The present lake occupies a shallow depression in Upper Karewa beds which are well exposed along the western shore, 1 mile north of Sumbal. Here the threefold division into yellow loessic silt, marl-bearing silt with sand, and gravelly sand is clearly seen. The sand dips 10° W., and the beds gradually increase in thickness and coarseness as they approach the hill front. These features express the littoral facies of the lake beds. How narrow this lake-shore belt was is indicated by the purity of the Upper Karewa silts at Dangarpur, 5 miles south of Manasbal Lake.

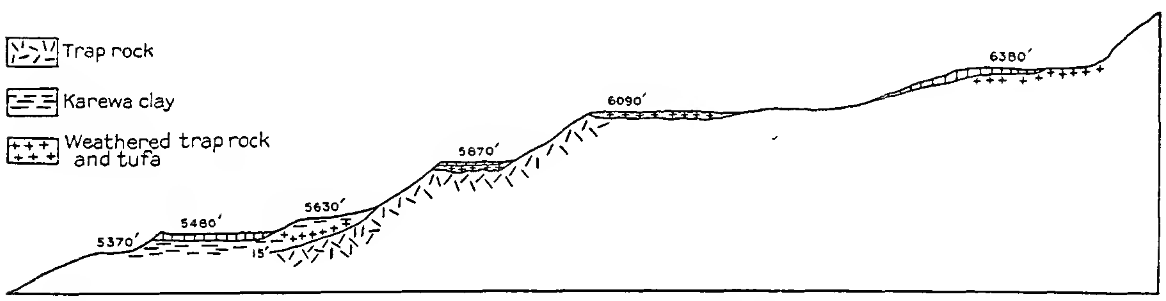


FIGURE 64A.—Composite slope profile between Watlab and Rampur, showing occurrence of loessic soils at various levels.

Here the lake beds form a dissected tableland which rises 115 feet above the marshes of the Jhelum plain. Conspicuous by its altitude and central position within the valley, this upland was chosen for settlement and worship over a thousand years ago. Potsherds litter the surfaces of these historic hills, and ruins of Hindu temples have crumbled into the loam, which here, as everywhere, coats the surface of the lake beds. Of these beds 50 to 60 feet are exposed. The purity of the whitish-gray silts, their fine bedding, and their horizontal position suggest the quiet-water deposits of the central part of the lake. The absence of plants and invertebrate remains in the silts contrasts with the wealth of fragmentary plants and shells in the underlying clay. This clay shows its fine lamination by limonitic bands, and its dark-gray color and tough consistency indicate a slack-water deposit accumulated under swamp conditions. The limonitic layers, I believe, originated from finely dispersed pyrite, which is still one of the minor mineral constituents of present-day Kashmir lake sediments.[1] Lamination is by no means restricted to these limonite bands but is found in the clay as well as in overlying silts. Marl appears here only in one section (see fig. 63, Wudin), but higher in the sequence, between yellow sandy silt and loam, lies a tufa layer of varying thick-

[1] Lundquist, 1936.

ness (6 inches to 2 feet). This tufa coats the pre-loam surface of the lake beds, sealing them off, so to speak, from the denuding influence of erosion. It is to this phenomenon that is partly due the preservation of Upper Karewa beds in the center of the valley. The formation of this tufa cap presents a major problem.

Tufa, as shown later, appears as a weathering product on certain terrace remnants and level spurs along the Himalayan slope. It is found on traprock at Ahateng, the isolated mountain south of Manasbal Lake, and all along the higher slopes above Wular Lake. Normally it is covered by loamy silt in which mature soil profiles (in places as many as three) suggest long and repeated weathering processes (pl. XI, 1). Therefore, a long time must have passed since the tufa was formed. As it occurs at all levels, in the valley center as well as a thousand feet above, its formation must have been due to a process independent of any lake stage. The tufa caps should not be confused with intraformational marl layers such as occur locally in eroded condition on the surface of the Karewa terraces. Figure 64B indicates that the formation of the tufa was intimately linked to an old soil profile of great maturity which is found at the base of the loamy silt. Previously I had pointed out that this top silt is of subrecent eolian origin—an interpretation which is substantiated by the composition of the top silt shown in figure 64B. Not only have the two dark carbonaceous subsoil bands a recent aspect, but the loam is also seen to rest disconformably above the tufa. This deposit lies on top of a weathered trap soil composed of reddish loam and trap fragments. The latter are totally leached and encrusted by carbonate of lime. On the slope surface this weathered trap is coated with tufa. These features indicate that concentration of lime took place subsequent to the weathering of trap. Colloids stained by hydrated ferrous oxide and mingled with insoluble or unfinished products of weathering, in which the feldspar constituents are dissolved, suggest a type of chemical composition characteristic of a warm-humid climate. At present no such soils are known to form in Kashmir, or, for that matter, in northwestern India. Tufa deposits, however, are common in either late Pleistocene or postglacial deposits of the northwest Punjab, where they contain abundant plant remains. In the two sections shown in figures 64B and 63 (Wudin sequence) can be recognized the same stratigraphic pattern in that the subrecent loam is separated from an older deposit by tufa. As the older beds at Wudin unquestionably belong to the Upper Karewa lake beds, it is obvious that the tufa was formed after the lake drained off and prior to deposition of the top loam. As this loam is a weathering product of more recent date, the tufa could have formed only on the dry surface of the lake beds. Concentration of lime is commonly found in silty subsoils under semiarid conditions, and from this fact it may be inferred that a drier climate prevailed in this region at one time, prior to the beginning of our geologic era.

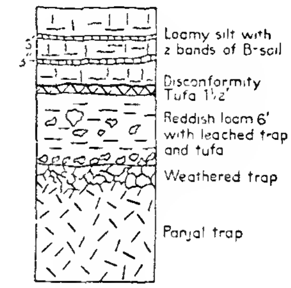


FIGURE 64B.—Soil profile on Panjal trap 1,100 feet above Lake Wular, on road from Watlab to Rampur.

The concretionary silt found in the lake beds at Wudin may belong to the same period of subsurface weathering, but on the other hand the lime concretions might well have been formed at a lower water stage. The greenish sand is undoubtedly homotaxial with the stage previously interpreted as first interglacial inwash. East of Manasbal Lake, owing to littoral position along the mountain flank, the greenish sand lies considerably higher than in the valley center near Dangarpur.

The Island Mountain South of Magam

Of singular interest is the position of Upper Karewa beds on an island mountain, 2½ miles south of Magam (fig. 65, pl. XI, 2). This isolated hill rises 628 feet above the valley floor and consists of Panjal trap mantled by Karewa beds. Good exposures are found along the path leading from Ratsun village up the slope to the Mohammedan shrine "Baba Hanifuddin," which crowns the hilltop. Beneath a 16- to 30-foot layer of brown loamy silt lies a whitish or light-yellow silt

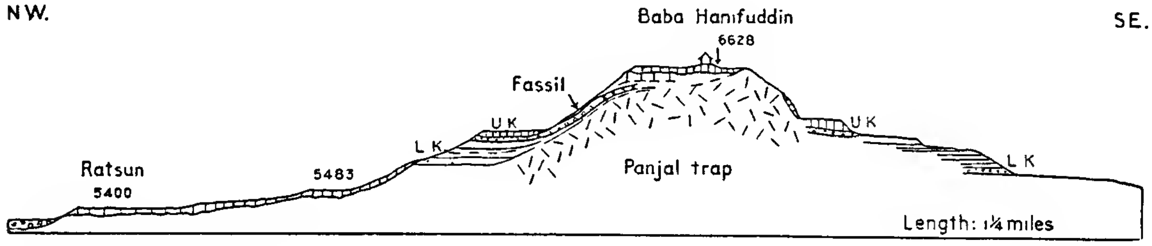


FIGURE 65.—Transverse section through island mountain near Magam. L.K., Lower Karewa beds; U.K., Upper Karewa beds.

with marl-bearing beds at the base. These beds in turn are underlain by clay and greenish sand, showing thus a stratigraphic pattern reminiscent of the previously described sections. But there are certain variations which demand discussion. A gravel layer, 4 inches to 3 feet thick, between the top bed and the yellow silt marks a new feature not recognized elsewhere. Its position above the green sand makes this gravel very much younger than the lower gravel observed in the section shown in figure 62, Sombur 1. As it was observed in several exposures around the hilltop, the gravel must have been deposited all around the hill at a time when this isolated mountain surmounted the lake bottom. The gravel constituents are quartzite, quartz, granite, and trap, all of which occur in the adjoining slope of the Pir Panjal, 6 miles southwest of the hill. Gravel layers between the top loam and yellow silt are not unusual in Upper Karewa sections of the Pir Panjal side. In this instance it is evident that the hill would have lain in the path of lake currents initiated by the Ferozepur and Sokhnagh river channels. From the descriptions of these valleys (see p. 136) it will become evident that during the second glaciation their rivers built a fan into the lake, and, as the hill is located precisely in the path of these streams, it is reasonable to interpret this upper gravel as a coarse glaciofluvial deposit of the second glaciation. As this gravel lies 324 feet above the lowest terrace of the surrounding plain and as, in addition, it tilts

away from the underlying bedrock with the rest of the lake beds, the island mountain must have been uplifted since the end of the second glacial period.

The Upper Karewa beds present here structure of a special sort which it is difficult to explain without assuming that they were part of the lake filling. Delta bedding as expressed in plate XI, 2, clearly belongs to the period of deposition during which the traprock was slowly buried under lake beds. This process evidently began at a time prior to the formation of the green sand, which we are inclined to correlate with the Sombur sand or first interglacial. Hence the basal portion of the sequence represents Lower Karewa time, at which the burying process of the trap hill must have proceeded far enough to allow the accumulation of green sand on a higher slope level. On top of this were piled 99 feet of lake deposits, which might have covered the hill for a short time.

But soft silt and clay are no match for a precipitous rock slope, and gravitational adjustment should have caused slipping on all hillsides. The angle of dip being 25° to 30° at many places, with the strata inclined in all directions, the Upper Karewas might here be likened to a dough dumped over a broad cone. Significantly enough, the bedding is in perfect adjustment to the underlying bedrock, so that a horizontal position is found only halfway down the hill, where older lake beds make a firm and even foundation. The upper portion on the steep slopes, on the other hand, is marked by sharp dips and turbulent structure indicative of gliding in unconsolidated condition. This slip structure might well have been contemporaneous with the deposition or have followed shortly after, but in any event it preceded the general tilting of the sequence. This tilt of about 10° is toward the valley and appears to be undisturbed by the slump structure. At first glance one would take it for a fan structure, but there is evidence to show that the hill rises on a shallow anticline in lake beds, which are exposed near Badgom and Waingam. This tectonic position might have caused a later slumping of lake beds, and yet from the relationship of the general tilt to the slump structure it would seem that the latter preceded the larger tectonic pattern.

Whatever fluvial inwash or eolian drift may have contributed to the formation of the beds, it is difficult to explain the variety of phenomena connected with this sequence unless lake conditions are assumed. Above all, it is the thinning out of the gravel layers and conversely the increase of the silt-clay beds toward the valley which prove their lacustrine origin. This can be noticed in plate XI, 2, where over a mile of exposures the silt almost doubles its thickness. Had rivers deposited this formation it would be expected that their fans, under the existing conditions, would have spread widely toward the valley and left an essentially gravelly and sandy record, as they do nowadays. The even bedding of the single layers and the complete mantling of the hillock also exclude any other interpretation.

Fossils, except a few shells of mollusks in the clay bands, are rare in this section. A well-fossilized tusk fragment was found in marl-bearing silt halfway up the slope on the path to the shrine Baba Hanifuddin. Although its incomplete state of preservation does not allow any generic determination, the texture of a

small proboscidean tusk could clearly be seen. From the topmost loam I collected a number of limb bones belonging to bovids (antelope and *Bos*). These were half fossilized, and one femur bears marks of artificial cutting with a blunt knife. It may be that the bones are derived from a kitchen midden, which opens prospects for discoveries of prehistoric remains on the hilltop.

Upper Karewa beds build dissected tablelands between Magam and Badgom. Loessic silt and marl-bearing silts with yellow sand and clay are exposed all along the slope toward the marshy flood plain of the Jhelum, suggesting a stratigraphic record similar to the one described above.

Upper Karewa Beds East of Baramula and Near Handawor

North of the delta which the Ferozepur River has cut into the Karewa tablelands the few sections studied are remarkable for the thickness of Upper Karewa beds, which in places exceeds 200 feet. In the lower portion of the exposures over 100 feet of greenish-gray sands and conglomerates with underlying laminated clays represent Lower Karewa beds, which are described in greater detail below. The gravelly sands under the plant-bearing yellow-gray clays doubtless represent outwash from the Pir Panjal slope. Here they seem to merge into coarse boulder deposits, which can be attributed to an early fan of the Lower Karewa beds. As figure 63 indicates (Durhom section), clay with fresh-water shells succeeds the sand, and marl layers follow. Above lies a complex, 85 feet thick, which is dominantly built of loessic yellow silt, and 16 feet of intermediate laminated clay. The silt is generally bedded, and its composition is diversified by fine bands of ocherous sand or clay, which can be seen clearly only on straight cuts such as at Durhom, or above Waingam. In color it resembles the "Potwar silt" of the Punjab, and anyone who passes the road cuts between Patan and Baramula might well be struck by this similarity. The top loam also is here thicker (12 feet) than at other places and is characterized by at least one carbonaceous layer of blackish color. This again I take to be an old soil which has yielded pollen grains of fir, spruce, pine, and hazel (Wodehouse and De Terra, 1935).

East of Baramula the beds are exposed along the main motor road, but complete sections are rare, owing to the cover of post-Karewa loam on several terraces cut into the lake beds on the left bank of the Jhelum. Sand or marl layers here make resistant edges in which slight tilting can be recognized.

The wide valley floor of the Pohru River, between Sopor and Handawor, is underlain by Upper Karewa beds. They appear along the river banks at Nanpur and farther upstream in the form of dark-brown silty clay and laminated silts. Whether the dark loam is of Pleistocene or younger age cannot be decided offhand, but in view of the wide extension of the lowest 15-foot terrace, it probably represents a postglácial or late glacial flood-plain deposit. At the southwestern outlet of the gorge through which the Pohru River enters the lower Pohru Basin, yellow silt with concretionary clay on top forms narrow flats 100 feet above the stream level. These tablelands extend beyond the gorge, surmounting the flood plain by at least 200 feet and continuing as far as the foot of the Kishenganga

watershed.[1] I did not visit this area, and therefore I cannot say whether these flats mark the combined thickness of Lower and Upper Karewa beds or not. The only reliable figure on the thickness of Upper Karewa beds in this region is given in the section at Hangah (fig. 66). Some 100 feet of clay and yellow silt overlie the tilted conglomerate and sand which we correlate with the Lower Karewa beds. Here slope wash conceals the lower part of the section, so that the base level of the conglomerate is not known. The total thickness may at best not be more than 110 feet. This figure may seem much too low to represent all of the Upper Karewa beds, but observations have proved that the sloping hills of the Pir Panjal flank are built mainly of Lower Karewa beds and conglomerates, with a thin veneer of Upper Karewa loessic silt and postglacial loess on top. As the valley flanks converge at Handawor it is also evident that the younger Karewa deposits, being the central fill of a basin syncline, should wedge out in this direction.

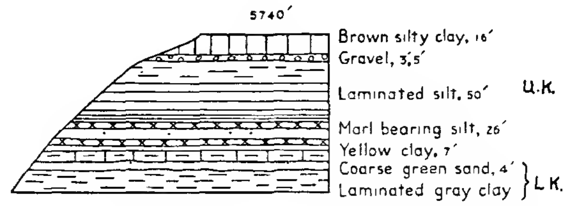


FIGURE 66.—Cross section through Karewa beds at Hangah.

The absence of true Upper Karewa lake beds in the higher hills near Handawor is of great significance, because it indicates that here, as elsewhere in the valley, they are restricted to levels not exceeding 400 feet above the present valley floor. The dark loam containing black soil zones observed at many places along the valley flanks, coating bedrocks and Lower Karewa beds alike, is thought to be a postglacial soil.

SUMMARY

If we summarize the interpretation of these sections, three major stratigraphic units become clear. Preceding these major units there was an accumulation of greenish sand and gravel in the form of fan deposits derived from fluvial outwash in Lower Karewa time. As on the Himalayan side the river deltas never reached the valley outlets, it is understandable that this sand and gravel layer represents well-sifted outwash from débris accumulated in the valleys. A disconformity separates these older beds from shell- and plant-bearing clays (Upper Karewas) that record a stage of quiet-water deposition. The following stage witnessed a lower lake level with marl beds and intercalated sand marking alternate stages of silting and lime concentration. During the third and latest stage loessic silt was precipitated, and in this process eolian, lacustrine, and fluvial agencies had their share. In general, therefore, the stratigraphic record is that of an inland lake with normal outlet, which underwent fluctuations of level and gradual silting. That this history was to a large extent determined by climate is evident from the superposition of these lake beds upon moraines of the second glaciation. (See Paterson's reports on the Sind and Liddar valleys.) The three stages, then, mark the beginning of that long interglacial period which followed the second Himalayan

[1] See Wadia, 1934, geologic map.

ice advance. The youngest lake beds clearly indicate that the lowering of the water table took place in a drier type of climate.

MORPHOLOGIC AND SEDIMENTARY RECORDS OF THE KAREWA LAKE SHORES

If there ever was a lake, the reader may ask, then there must also be on record the markings of its various water tables along the shore. Where are the shore lines and ancient beach marks of this Upper Karewa lake, and if they are present how can we distinguish them from those older beaches left during the Lower Karewa lake stages?

Data on oscillatory and larger fluctuations of lake level, clearly recorded from the sedimentary filling of the basin, are available also from the northeastern flank of the valley. Here beach marks and gravel-strewn shore lines appear at numerous places. The geologic map shows that these features are restricted to the Himalayan slope and absent on the Pir Panjal side, except for certain sets of

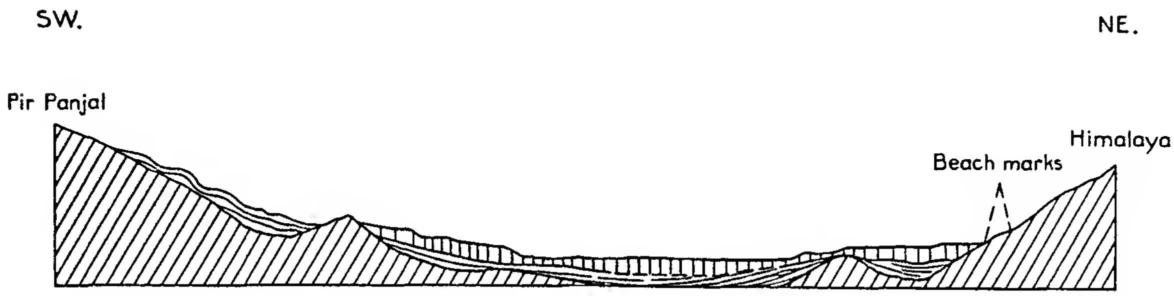


FIGURE 67.—Generalized cross section through Kashmir Basin. Upper Karewa beds, vertical lines; Lower Karewa beds, wavy lines.

low beaches cut into the eastern slopes of the Karewa terraces, where they border marshes and flood plains. These low beaches, then, are obviously younger than the Karewa Lake and therefore cannot be associated with the higher beach levels of more ancient origin. How are we to explain this asymmetric distribution of shore features in the Kashmir Valley? Normally one can expect to find a more or less uniform record of beach marks on the slopes of an inland lake basin. The one-sided preservation of shore lines here calls for a special explanation.

On a previous occasion I have called attention to relatively recent earth movements that caused differential uplift of the Kashmir region. The Pir Panjal flank, especially, experienced intermittent uplift, and in the following chapters I present evidence for an infra-Pleistocene diastrophism as recorded by the fold structure of Karewa lake beds at the foot of the Pir Panjal. This structure can be understood only if we assume, first, an uplift with folding of the Lower Karewa beds prior to deposition of the boulder gravels belonging to the second glaciation; and, second, a younger phase of tilting following deposition of the Upper Karewa series. This tectonic process led to the formation of an unconformity in such a manner that the Upper Karewa beds came to rest on the eroded surface of folded Lower Karewas. Figure 67 gives a general picture of the structural relations of

the two lake series, indicating the existence of two lake basins, of which the younger rests against an older basin that is strongly tilted along the Pir Panjal slope. Obviously the shore lines of the older lake might well have been preserved on the Pir Panjal slope, but subsequent erosion and morainic débris would have destroyed these records, and as for the younger lake, its water table rested against older clay and silt beds in which preservation of beaches must have been short-lived, because post-Karewa erosion was very active in this region. On the corresponding Himalayan slope conditions for preservation were more favorable. Here the lake beds are very little disturbed and the lake would have left its markings, throughout the lake period, on solid bedrock, which at that time presented a fairly precipitous high wall. Subsequent uplift on this side would have carried the more ancient shore features to higher levels, which further prevented extinction. Such elevated beach marks were found at a few places and generally between major valley outlets where they escaped glacial erosion.

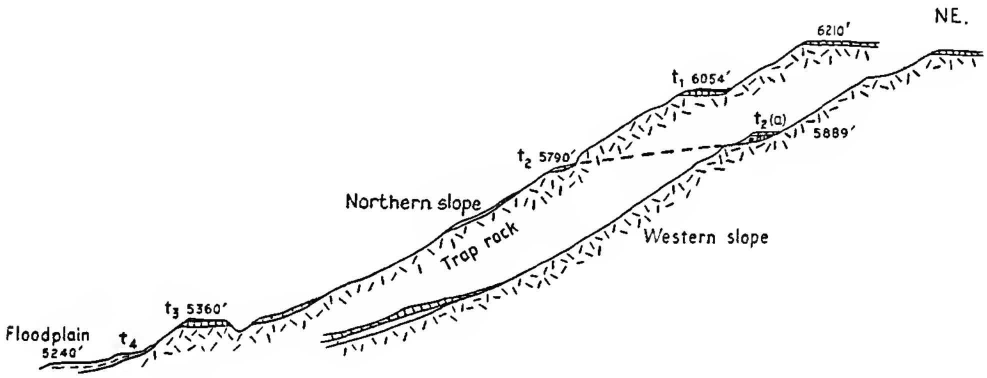


FIGURE 68.—Slope profiles of Takht-i-Suleiman, near Srinagar.

On the Himalayan slope, then, we may expect to find the shore lines of both the Lower and Upper Karewa lake stages. Instantly the question arises whether the morphologic records will allow us to differentiate between these major periods and whether it will be possible to assign a certain set of beaches to a particular stage in the history of the Karewa Lake.

BEACH MARKS

Takht-i-Suleiman.—One of the most accessible and striking records of Karewa Lake shores is found on the higher slopes of Takht-i-Suleiman ("the Mountain of Suleiman"), which surmounts the city of Srinagar by a little over 1,000 feet (fig. 68, pl. XI, 3). It is an isolated portion of a spur made of Panjal traprock, which projects boldly from the precipitous Himalayan slope. Dainelli (1922, p. 494) has commented on the existence of beach levels in the vicinity of Srinagar. He observed one at 1,650 meters, which is 45 meters above the flood plain at the Dal bridge, and a higher one below the mountain top. These beaches apparently are the levels marked "t_1" and "t_3" in figure 68. Our level t_2 lies 550 feet above Srinagar and can be clearly seen as a marked line on the northern slope above Gagribal (pl. XI, 3). Viewed

from the Dal Lake this level displays a conspicuous dip of 8° SW., and a comparison between the northern and western mountain slopes reveals clearly a displacement of this beach line by nearly 100 feet over a distance of 1¼ miles. This beach is cut several feet deep into the trap and is strewn with gravel 10 inches to 2 feet thick. On the western slope the gravel is overlain by several feet of yellowish-brown clay with lime concretions and pieces of weathered trap. At one place I observed a cliff, 3 feet high and slightly hollowed as if made by wave action.

A higher beach line is found 264 feet above t_2. This ledge widens on the south-western slope to form a broad terrace covered by a thin mantle of yellow loam with a dark-stained soil zone on top. This resembles the top loam above the Upper Karewa beds to such a degree that one cannot hesitate to interpret it as of post-Karewa age and eolian in origin. Indeed, the presence of this formation 1,000 feet above the valley floor is in itself corroborative proof for the contention that the brown loam with soil layers represents wind-drifted silt which here became mixed with weathering products from traprock. The steepness of the slopes and the fact that the loam is restricted to the flat ledges argue against any other interpretation, such as lacustrine or fluvial origin. Only the thin gravel cap on t_2 can be assigned to a lake stage, as its occurrence is confined to this beach line, which runs all around the mountain. Indications of smaller beach marks are preserved locally below t_2, but rock débris has blotted out most of these records.

Under normal conditions raised beach lines may give information concerning the former extension and height of the water table. At this locality they might indicate the height at which the Karewa Lake stood at the time of its greatest extension. Because of the tilted attitude of the beach lines it is hardly possible to estimate the lake depth. Even if we assume that the bench at 5,790 feet represents the undisturbed elevation before tilting occurred, it is still uncertain to what extent the Himalayan slope as a whole had undergone uplift. Evidence has been cited to prove that such movements had actually taken place in post-Karewa time (p. 67). In addition, it is unknown how thickly the bottom deposits had accumulated during the early lake stages. If the Sombur quarry sequence can be taken as representing a typical shore deposit, then the Lower Karewa shore record amounted to a few feet only. This could hardly have been the case if the water table stood 500 feet above the valley floor, as t_2 indicates. The tilted position of the beach lines sheds some light on their relative age and origin. As shown in the following sections, the Karewa lake beds show an accumulated effect of uplift and folding, prior to the deposition of the conglomerates which we assign to the second glaciation. This strong disturbance must have caused displacement of those lake levels which had formed during the Lower Karewa lake stage. As this was the time of the greatest accumulation of clay deposits in undisturbed waters, we may infer that it coincided with the period of greatest inundation prior to the second ice advance. The highest beaches on record, therefore, should belong to this Lower Karewa stage, and the lower one (t_3, fig. 68) might represent a younger Karewa water table. Now, inasmuch as the Upper Karewa beds near Srinagar are undisturbed, it is evident that the higher beach lines must have been previously

tilted, and if so they could have originated only during the earlier lake phases. True enough, there are indications of later uplifts along the Himalayan slope, but if these had affected the regions 3 miles off the valley flank, one would expect to find a pronounced dip in the Upper Karewa beds, and of this there are no traces.

The lower terrace (t_3, fig. 68) is 120 feet above the flood-plain level. It is covered by 7 feet of loamy silt in which is found pottery débris of historic date. Near Gagribal appear true Upper Karewa beds whose level approaches the terrace remnants by 20 feet. Very likely, then, the third terrace belongs to a much lower lake level of Upper Karewa time.

Bren spur.—On the eastern shore of Lokut Dal, south of Bren village, is a long spur made of Panjal trap, Agglomerate slate, and Gondwana shales. Its northwest end rises over 400 feet above the lake shore and exposes at the traprock quarries a set of gravel-strewn beaches (fig. 69). Upper Karewa shell-bearing clay (2) is underlain by 5 feet of gravel (1), whose angular constituents show little wear. The clay is covered by dark granular clay with soil layers (3), the same stratum

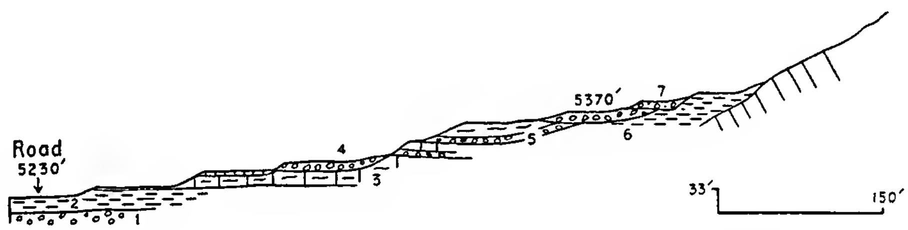


FIGURE 69.—Cross section through lower slope of Bren spur, with beach gravels.

which is conspicuously exposed on the main road a quarter of a mile south of Bren. In the upper gully exposures, the clay is overlain by a yellow impure loam (5), in which gravels with torrent bedding increase rapidly toward the higher slope. Beneath appears again a granular clay of bright-yellow color. Strata 1, 2, 3, 5, and 6 clearly represent the Upper Karewa sequence (155 feet thick) as is indicated by the presence of fresh-water shells belonging to *Valvata piscinalis* (O. F. Müller) and *Lymnaea auricularia* (Linn).

Of particular interest are those gravel patches (4 and 7, fig. 69) which are associated with beach marks. Altogether seven beach marks are here cut into the Upper Karewa beds, ranging in width from 20 to 100 feet. The highest level in this section is 170 feet above the flood plain, and the widest beach 110 feet above the ground level, which might correspond to terrace 3 of figure 68. Layer 4 is a shingle deposit banked up against layers 3 and 5, and layer 7 is a small-sized gravel, restricted to the beach and composed differently from the underlying fan. Were it not for these gravel patches on the beaches, one might hesitate to interpret these ledges as raised beach lines, because abandoned rice fields might have left a similar morphologic record. Deceptive as the traces of ancient rice terraces can be, there is no question as to the genuine beach origin of these features at Bren spur, especially when one examines the upper slopes.

Along the flank facing Bren village at least six higher ledges (pl. XII, 1) can be recognized. This set of beaches is separated from the lower one by some 50 feet of fan-covered slope surface, on which no levels are preserved. The higher set occupies the spur up to 5,500 feet, and the levels are here on the average 10 feet apart from each other. Toward the top of the isolated knob yellow and brown clay mantles the surface, in much the same fashion as at Takht-i-Suleiman. The surface of this broad top is strewn with slate and tufa fragments. The brown loam continues up to 5,600 feet, resting as a thin mantle on bedrock. Above 5,600 feet no clear traces of beaches were found.

The fact that these upper beaches are cut into brown loam might suggest artificial construction, but the association of tufa with the upper level and scattered patches of gravel argue against this suggestion. It seems rather as if we had to deal with a uniform set of at least 15 beach lines between 5,240 and 5,500 feet. All of these lines seem to belong to a period of progressive lowering of the Karewa

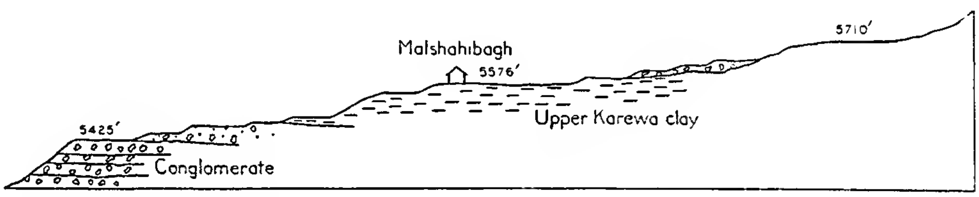


FIGURE 70.—Cross section of lower slope near Malshahibagh, with raised beaches now cultivated. The conglomerate is the first glacial outwash.

Lake level. The beaches resemble the beach lines formed around the present-day highland lakes of Indian Tibet.[1] Whether they have been displaced by uplift or not could not be ascertained.

Wuyan.—Three miles northeast of Pampur lies the village of Wuyan, known for its sulphur springs and ancient bathing tanks. On the western slope of the spur (marked 5,960 feet on sheet 43 T/16; C3) Upper Karewa beds rest against the mountain, which displays over twenty minor beach lines (pl. XII, 2). The top silt layer is at 4,290 feet, and the highest beach observed is at 5,560 feet. The beaches are commonly 30 to 40 feet wide and regularly spaced. Most of them are cut into the lake beds. Here also one might at first suspect an artificial origin, but the uppermost beaches are faintly cut into the limestone, on whose slopes there are at places low cliffs in which the otherwise rough surface is smoothed and pitted. It is inconceivable that the natives should ever have constructed rice fields in the loamy soil on the mountain side when they had wide tracts of land in the adjoining lowlands at their disposal. Hence the entire set might be taken as representing a continuous record of progressive shrinkage of the Pleistocene lake.

Malshahibagh.—At the outlet of the Sind Valley, 1¼ miles southeast of Gandarbal, the Upper Karewa beds show several terrace flats, of which the largest is at 5,576 feet, or 276 feet above the valley floor (fig. 70). This terrace is partly covered by an alluvial fan which originates on the higher mountain slope. There

[1] De Terra and Hutchinson, 1934.

are altogether ten terraces, but none of these can, with absolute confidence, be interpreted as raised beaches, for no beach gravels or cliffs were observed. Besides, there are traces of ancient cultivation all over the surface of the lake beds. It is obvious that here the natives utilized the higher ground in order to escape flood conditions, which arise almost annually during the high-water stages of the Sind River. Nevertheless these features are conspicuous enough to be put on record.

Manasbal.—East of Lake Manasbal, on the right slope of a narrow valley called Lar Kol and about 200 furlongs from the present lake shore, I observed a set of eight beaches. The lowest is at 5,562 feet, and the highest at 5,700 feet (fig. 71). All are cut into brown-yellow silt and brown clay, indicating the highest Upper Karewa beds. The upper four terraces have a thin veneer of fine gravel. The pebbles, being well rolled, give the impression that they had been washed off the slope and then deposited on the beaches.

Similar shore features are found on the northern slope of Ahateng Mountain, an isolated hill which surmounts Lake Manasbal by 1,074 feet. The levels here match closely with those of the Lar Kol locality, and figure 71, B, indicates that there are at least eight beaches. A comparison with the former record (fig. 71, A) shows that both sets supplement each other, so that the total number of raised beaches is ten. In addition to these, there are higher beaches which were not measured, as their incomplete state of preservation does not warrant a clear presentation.

Eastern shore of Wular Lake.—A few miles north of Lake Manasbal, beach lines and terraces appear all along the lower mountain slopes. At Takia, for instance, large fans surmount the narrow belt of Upper Karewa beds. These show an impressive set of ledges, ten of which were surveyed (fig. 71). This record is very similar to the one from Wuyan above cited, and it matches another set of low beaches cut into the front of a large fan near Zewan village.

At Gund-i-Sudarkut, a village situated on a prominent spur 13 feet above the Wular Lake bed (5,190 feet), bedrock is overlain by a coarse breccia and subangular gravel suggestive of littoral origin. The promontory of bedrock southeast of Gnour has eight beaches between 5,280 and 5,360 feet. Here also, between 5,400 and 5,500 feet, were observed a few narrow ledges which are cut into bedrock, apparently representing levels of the Upper Karewa lake.

To a similar period might belong the beaches found near Wodhapur on the Pohru River, north of Handawor. There are seven altogether, the lowest at 5,485 feet and the highest at 5,672 feet. The flood plain of the river is here at 5,230 feet.

Conclusions.—In summarizing these data it is evident that the Karewa Lake has left unmistakable beach records along the Himalayan slope. Figure 71 gives a comparative view of the raised beaches. Three sets can clearly be recognized—the highest terrace (or terraces) above 6,000 feet, as recorded on Takht-i-Suleiman; the beaches and terraces ranging in height from about 5,500 to 5,730 feet; and finally the beaches under 5,420 feet. The lowest beaches make a characteristic set of at least 18 levels, all of which are cut either into Upper Karewa clays or into fan deposits. At a few places they are recorded in bedrock. Whether all of these

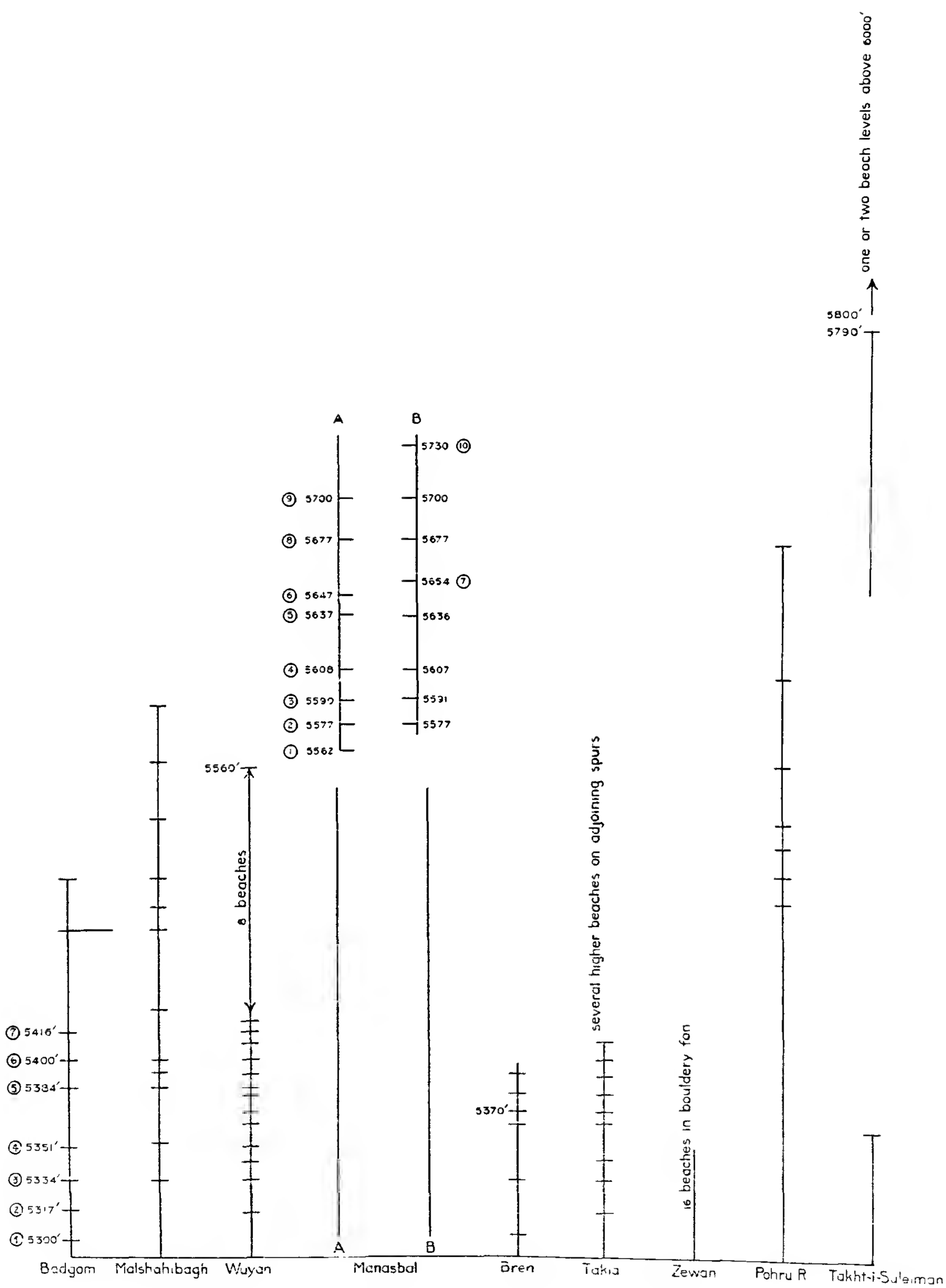


FIGURE 71.—Comparative levels of observed beaches of ancient Karewa Lake.

belong to a Pleistocene yet post-Karewa lake period or whether they are postglacial is impossible to prove until additional observations are available. However, had these lower beaches been cut in post-Pleistocene time, when river floods might have inundated the valley, one would expect to find traces of a younger lake formation. What little information there is points to the existence of slack-water deposits beneath the marshy swamps now occupying vast tracts of land north and west of Srinagar. At Badgom and Baramula the Lower Karewa slopes facing the valley center are in places mantled by sandy loam, and similar deposits were observed forming a low terrace, 10 to 15 feet above the Jhelum River. Near Sombur, I found pottery and waste flakes in this lowest terrace which could in no case be older than neolithic. Whether the lowest Jhelum terrace is correlated with the slack-water deposits mentioned above is unknown, but I believe it unlikely, for a shallow inundation of such recent date would have left clear sedimentary records all over the valley lowlands. Even if one assumes that the meandering Jhelum had subsequently eroded most of this formation, that it would have removed the entire record is unthinkable. Hence, it is more likely that the lowest beach set represents an older period of inundation connected either with the last stage of the Karewa Lake or with a late Pleistocene flooding of post-Karewa time. If so, the interval between the deposition of younger lake beds and recent time would have been sufficiently long to allow for destruction or obliteration of post-Karewa sediments. The close and rather regular spacing of these beaches indicates an accelerated process of lake shrinkage, and it might well be that this took place immediately prior to the spilling of the Karewa Lake.

The middle set of beaches is older and must have originated during late Upper Karewa time. Then the water table still stood several hundred feet above the present valley floor, but for reasons discussed elsewhere no inference can be drawn as to its exact height. The higher beaches in this set, lying above 5,600 feet, might well indicate the stage of clay formation as marking a deep-water deposit, while the lower ones could represent the time of recession, during which the marl-bearing beds were laid down.

The high levels at Takht-i-Suleiman are unquestionably the most ancient beach records known. Their Lower Karewa or early Pleistocene age is discussed above. The sedimentary and fossil record of this important period is demonstrated farther on. Only in connection with this demonstration will it be possible to visualize the magnitude of the inundation in the Kashmir Valley during the Ice Age.

D. GLACIATION OF THE NORTHEASTERN SLOPE OF THE PIR PANJAL

FIRST GLACIATION

General Features

Traces of the oldest mountain glaciation in the Pir Panjal are rarely found, and deposits of truly glacial origin are preserved only on the highest remnants of leveled elevated surfaces. Such deposits are coextensive with the remnants of the mature preglacial relief, as represented by the highly elevated tract of Tosh Maidan (11,000 feet) and by leveled spurs and headwater portions of transverse

valleys which are unconsumed tracts of the old land surface. These glacial deposits consist of thin patches of weathered clay moraines. Spread like a thin mantle over the highest slopes and even surfaces, they might easily be mistaken either for débris derived from physical weathering in high altitudes or for glacial deposits of recent date. Their greater age, however, can be deduced from the following observations:

1. The general distribution (see pl. LV) of the oldest clay moraines is at levels between 12,000 and 12,500 feet. They are found neither in the highest trough

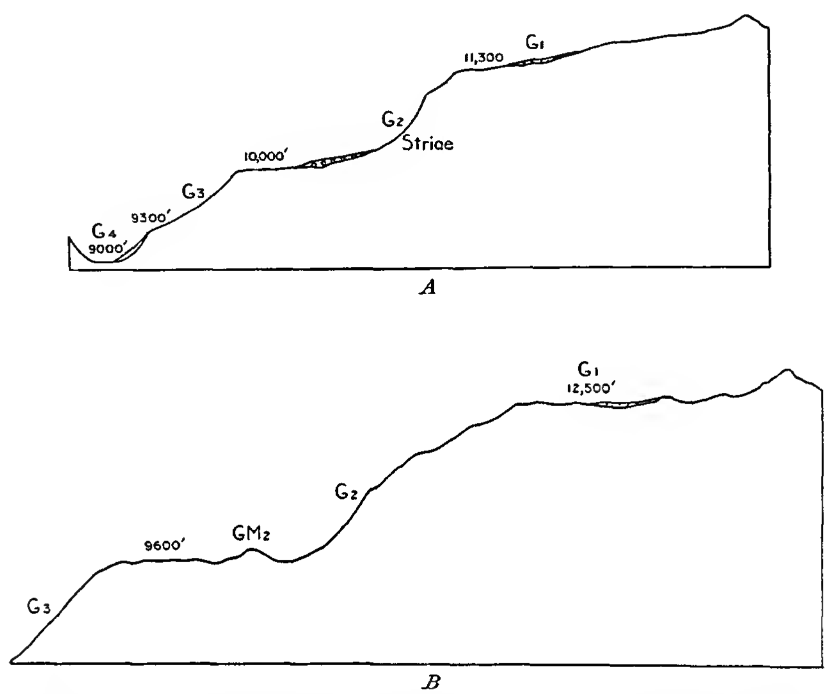


FIGURE 72.—Composite slope profiles of Harseni Valley (*A*) and upper Ferozepur Valley (*B*). G1, first glacial deposits; G2, second glacial deposits; GM2, second ground moraine; G3, third glacial deposits; G4, fourth glacial deposits.

valleys of the summit region nor in any of the deeper valleys. Their realm is the elevated tract between the summit range and the glacially scoured area above the Karewa slope surfaces.

2. Wherever a composite glacial slope profile is preserved (fig. 72) these clay moraines lie above the trough shoulder of the second glacier, which in most places is clearly pronounced above the deeply scoured trough. Figure 72 illustrates this relation, and the panorama of the Chinamarg region above Tosh Maidan (pl. XIII) reveals a similar picture.

3. The state of preservation of these clay moraines is such as to indicate long exposure to both physical and chemical weathering agencies. Limestone or slate boulders are rarely found, although both rocks are prominent in the formational composition of the central range. Occasionally they were encountered in a state of complete disintegration, indicative of long exposure to weathering. Feld-

spar and mica constituents in igneous rocks are also decayed, and the clay in which the boulders are embedded is full of disintegrated particles of rocks and minerals. The clay matrix is impregnated with angular quartz particles derived from crumbling boulders. Locally, also, there are bands of iron-stained clay. These phenomena make it possible to distinguish these deposits from younger and particularly from recent morainic débris.

4. No instance is known which would indicate a correlation with boulder moraines of younger origin; in fact, no terminal or lateral moraines have ever been found associated with the oldest glacial deposits.

5. In contrast to all moraines of later date, the clay moraines are never found in trough valleys or remnants of such valleys but occur on flat surfaces, such as characterize the highest interstream divides.

One of the most striking characters is the thinness of the formation. At Tosh Maidan it is barely more than a thin veneer, some 20 feet thick, and on the high spurs along the upper Harseni Valley, above Sedau, it reaches 30 feet. Glacial striae or boulders are missing, as igneous rocks of coarse texture rarely register such marks. Many faceted boulders were found, but in view of the scattered occurrence of most of the boulders, it is difficult to gain a complete picture of the intensity of the ice action. It seems that they experienced relatively little wear during their ice transport.

These characteristics all tend to indicate a weak mountain glaciation localized to leveled regions adjoining the watershed range. The sporadic distribution of the clay moraines, on the one hand, and their total absence from regions below 10,000 feet, on the other, suggest that their deposition was due to local glaciers in the highest tracts of the range. Such restricted glaciation is nowadays typical of the high ranges of Tibet, where short glaciers often tend to form piedmont glaciers, reminiscent of local ice caps.[1] From the foregoing discussion of the preglacial relief (section A), it is evident that the Pir Panjal must, at that time, have had a relief somewhat similar to that of the recent Tibetan highland, and, although it was much less elevated, exposure to monsoon winds might have permitted the local formation of very small glaciers or of névé fields. As these would have spread out over the less dissected surfaces, the ice should have left ground moraines on them. These moraines could have escaped denudation only in regions untouched by subsequent erosion—that is, on elevated plateau remnants and level divides. The corresponding boulder moraines in the high range had little chance for preservation, for they must have fallen prey to the scouring activities of later ice advances. Hence the sporadic occurrence of these oldest moraines, which, by the nature of their peculiar formation, contrast remarkably with the records of the strong first valley glaciation found on the Himalayan slope. (See sections by Paterson.)

Fluviatile Deposits (First Glacial Outwash Fans)

In most examples of valley glaciation fluvial outwash and fan formations occur toward the lower valley tract. However, owing to the peculiar elevated position

[1] De Terra, 1934, p. 29.

of the first glacial deposits in this region and to subsequent erosion, we cannot expect to find outwash gravel in the valleys. Only along the foothills are there coarse fan deposits, which underlie the Lower Karewa lake beds. Their position relative to this first interglacial formation is similar to the one reported by Paterson from the Sind Valley (figs. 10, 11), and hence we do not hesitate to assign these basal gravels to the first glaciation.

For instance near Sedau, at the outlet of the Vishav River, the Lower Karewa clays are underlain by a series of brown to pink gravels and sands which are faulted against Paleozoic slate (figs. 73, 86). The thickness exposed is somewhat in excess of 86 feet. The pink gravel and sand show cross-bedding and are tilted to an angle of 55°. This dip decreases quickly downstream to 25° and 20°, and at the first bend of the river laminated clays are seen resting conformably on the older fan formation (pl. XIV, 3). A thousand feet downstream from this river curve, the Lower Karewa clays are overlain by similar gravel, and both series are tilted to 35°. This gravel is of finer texture and much thinner than at the former place. It also merges quickly into brown and pink clay. As it lies on top of the lake beds, it cannot very well be considered part of the older fan. Also the lake beds are here several hundred feet thick, thus indicating a long period of lake deposition, following accumulation of the large fan. The similarity of these fans, both in color and in composition, suggests that they (with the lake beds) belong to one long cycle initiated by the formation of a fan. This, we are inclined to interpret as an outwash deposit of the first glaciation. Its formation clearly preceded the lake stage, and as there are numerous localities on both valley flanks where glaciofluvial outwash underlies Lower Karewa beds (Malshahibagh and Rimbiara Valley conglomerate), it is suggested that this fan belongs to the same stage. Although the correlation between glaciofluvial gravels and the oldest terminal moraines is recognizable in the Sind Valley, there are as yet no places known in the Pir Panjal where a similar association occurs. As previously stated, this is due to the great difference in elevation between the ground moraine of the first glaciation and the present valley outlets. The sequence is here clearly displaced and the faulted condition of the fan near Sedau is proof of a profound tectonic disturbance.

Another gravel was met with in the adjoining Rimbiara Valley near the village of Hurapur. On descending from the higher terrace to the village, the road exposes firmly cemented conglomerate that apparently underlies the lake beds (fig. 89), which are visible on the opposite bank. This conglomerate resembles the Malshahibagh conglomerate of the Sind Valley more closely than the fan deposit in the Vishav River. All components are thoroughly rolled, which accounts for the absence of striated or faceted pebbles. Upstream the river has cut into an ancient valley fill which emerges from underneath the lake beds. It is essentially the same formation as near Sedau, but much thicker and coarser. Boulder-bearing conglomerates and dark half-cemented brown sands make an impressive pile of river deposits some 900 feet thick. This, then, represents the true thickness of the older deposits more accurately than does the Sedau section, where they were strongly faulted and thinned out.

About 1¾ miles southwest of Baramula, on the eastern slope of a forested ridge, a huge gravel fan was found which is overlain by plant- and shell-bearing clays (fig. 75A). The basal conglomerate of this formation is exposed about 600 feet east of the electric-power line that crosses the ridge on the pass road from Mirhar to Baramula. Round pebbles of green quartzite, gabbro, trap, and slate make up the larger portion of rock fragments, all of which are derived from the Pir Panjal slope. The larger pebbles measure 6 inches in diameter; smaller ones, 2 to 3 inches. The conglomerate is of a brown, somewhat pinkish color and slightly cemented. Cross-bedding alternates with evenly bedded layers of brown sand which individually measure 3 to 6 feet in thickness. This fan can be followed for 700 yards down the eastern slope, where it dips 12° NE. Its total thickness may approximate 162 feet. As the basal layers lie 800 feet above the valley floor of the Jhelum River, it is difficult to account for the high altitude of the fan unless uplift and tilting of the underlying bedrock are assumed.

That such uplift has actually taken place is discussed in another section (p. 127). It should be noted, however, that the lake beds overlying this fan are tilted, from which we infer that the fan itself is in a disturbed position. Even if this is assumed, it is difficult to explain the variety in the pebble composition, which reflects denudation of a whole range of formations not found in the underlying rock floor. In other words, the fan, being of fluvial origin, required for its formation a relief wholly different from the present land surface. Its fluvial source might be looked for in a stream course, ancestral to the present Mudri River, a tributary of the Jhelum, which now flows 1 mile southwest of the ridge. A lower position would have brought the ridge into the center of a delta which the ancestral river built at its confluence with the Jhelum. This situation doubtless preceded the deep trenching of the Jhelum Gorge below Baramula and thus required a period of filling prior to later uplifts. Whether this stage coincided with the beginning of the Pleistocene is impossible to prove, but it should be remembered that the Tatrot stage of the Upper Siwalik represents precisely such a time of heavy accumulation of rock débris,[1] following an uplift of the Himalayan Range. The absence of glacial material in this fan is no valid argument against the assumption of its early Pleistocene age, because the adjoining Pir Panjal is here, even now, lower than at any other place—a fact which makes the idea of its having been glaciated during that time very improbable.

At other places, notably on the mountain slope 3 miles to the southwest of this fan, there is similar débris underlying lake beds. The deposits make badly stratified subangular gravels and breccias, which at places reach 100 feet in thickness. Good exposures are found in a gorge 1 mile south of Malapur. The breccias are made up of angular débris embedded in brown sandy loam, and they were found to be nonstratified along the higher slope of the valleys. Yet in the valley they show coarse cross-bedding, indicative of turbulent conditions. The resemblance of these deposits to the "loam breccias" or solifluxion soils nowadays formed in the cold climate of higher Tibet is so striking that one is tempted to

[1] See De Terra and Teilhard, 1936.

regard these fossil breccias as products of a similarly cold age. Its soils may be derived from subarctic weathering in a periglacial region where great diurnal temperature changes and repeated desiccation of sporadic snow blankets make for accumulation of solifluxion and structure soils. Such an interpretation of the fossil breccias appears to lend support to our suggestion concerning the early glacial age of these deposits.

FIRST INTERGLACIAL PERIOD

Erosion

Whatever the effects of preglacial uplifts were on the mature relief of the Pir Panjal, it is evident that they are overshadowed in importance by events that followed the first glaciation. We refer here especially to the convex slope profile above the trough scoured by the second glaciers and to the general dissection of the older planed surfaces. Plate XIII shows the relation of the second glacial trough to the plateau level in the right background (13,500 feet), on which lie clay moraines of the first glaciation. Between is a convex slope which here may be 400 feet high, but in other valleys it is as high as 500 feet and more (fig. 72, *B*). In all major Pir Panjal valleys of sufficient altitude, the wide troughs of the second glaciers lie deep beneath the plateau remnants and moraine-covered spurs. True enough, these glacial valleys (the first and highest in the sequence of glacial troughs within this region) have, in the course of glacial time, witnessed both erosion and denudation. Their flanks are covered by fans; their slopes are dissected and must have undergone a certain reshaping, but all these processes could not diminish the visual effects of an erosion that preceded the first true valley glaciation (second Himalayan ice advance). In fact, it is imperative to postulate this erosion, as the following glaciation could never have had such striking morphologic effects unless previous erosion had provided channels of sufficient magnitude to promote valley glaciation.

Unquestionably, erosion was most effective along the lower stream courses, which accounts for the fact that the convex slopes below the plateau level are greater than in the valley tracts. Such differences in the effects of dissection upon the older relief indicate a nongraded stream profile in which the rivers attained grading only after they had reached the local base level of erosion—for example, the Kashmir Valley. What the actual extent of erosion was at this period is difficult to estimate, for weathering and slope wash are very active at such altitudes, and consequently the glacially scoured flanks of the upper troughs can mostly be determined only by their general shape. Generally there is a distinct nick in the upper profile (fig. 72), which we take to be representative of the nonglaciated remnant of a valley slope antecedent to the second valley glaciation. This convex slope, however, cannot be the sole remnant of the earliest valley, because of the great depth of the second trough (G2), which undoubtedly is not entirely the result of glacier erosion. Hence, the upper glacial trough should, in part, also date back to this interglacial erosion.

Proof for this contention is the occurrence of Lower Karewa lake beds in headwater portions of such valleys as existed prior to the general inundation of the basin. In the Rimbiara Valley, for instance, near Hurapur, Lower Karewa clays are exposed 4 miles upstream from the valley outlet, and in the upper Ningle Valley, near Gulmarg, plant- and fish-bearing clays underlie, at 8,600 feet, the floor of the second trough. In view of the fact that these highly elevated remnants of lake deposits can, on paleontologic and lithologic grounds, be correlated with true Lower Karewa beds, it is evident that the older Karewa Lake inundated a dissected slope of the Pir Panjal in which the major valleys had already been established.

This rejuvenation of the Pir Panjal in early Pleistocene time might have been begun well back at the beginning of the Pleistocene or at the end of the Pliocene. Dissection had at that time apparently not proceeded far enough to obliterate the planed surfaces along the watershed on which the first glaciation concentrated. The lower relief units slowly consumed this preglacial land form by progressive dissection and widening of the lower stream courses. At this period occurred the first inundation of the valley basin of Kashmir, as was recorded by the Lower Karewa lake beds.

Lower Karewa Lake Beds

The stratigraphic term "Lower Karewa lake beds," introduced by Lydekker (1883), is used for a thick series of gently folded lacustrine deposits on the Kashmir flank of the Pir Panjal. Godwin-Austen (1864) had already noted that this formation presents problems of great significance for the younger geologic history of the Himalaya. The previous observations on tilting, thickness, and fossil content of the Lower Karewa beds were later substantiated by Middlemiss (1910, 1924), who considered them to be of Pliocene-Pleistocene age and linked with the Quaternary glaciation of Kashmir.

The formation extends along the Kashmir slope of the Pir Panjal over a distance of 80 miles and a width of 8 to 16 miles, but, as mentioned above, it also occurs locally on the Himalayan slope. Both in extent and in thickness it outranks the Upper Karewa beds and therefore deserves detailed description. Needless to say, field observations were gained from valley exposures only, because of the forested nature of intermediate tracts. The stratigraphy, therefore, had to be compiled from numerous sections exposed along the slopes of transverse valleys. Owing to the fact that the formation was laid down on a dissected slope, its thickness varies from place to place, and so do the several facies of the formation. Notwithstanding these handicaps, an attempt was made to group the entire sequence into several horizons.

Stratigraphy.—The Lower Karewa lake beds can be defined as a fluviolacustrine formation which is unconformably overlain by glaciofluvial outwash deposits of the second ice advance (Karewa gravel) and underlain by either bedrock or fans older than the first interglacial stage.

1. Basal clay series: In the deepest exposures along the Rimbiara River above Hurapur and on the Vishav River south of Sedau the gravelly sand of the

underlying fans is overlain by a thick sequence of dark and gray clays. They are laminated throughout and contain a great number of greenish-gray sandstone layers, each of which ranges from 1 to 4 feet in thickness. Above Hurapur their apparent thickness exceeds 1,000 feet, but this figure is greatly reduced if account is taken of the repetition of strata due to folding and faulting. The true thickness is perhaps 600 feet. Most of the clay is exceptionally pure and tough, but the finer laminae consist of gray silt and fine sandy silt. The sandy layers are slightly cemented and weather out in resistant bands in which the even bedding is clearly

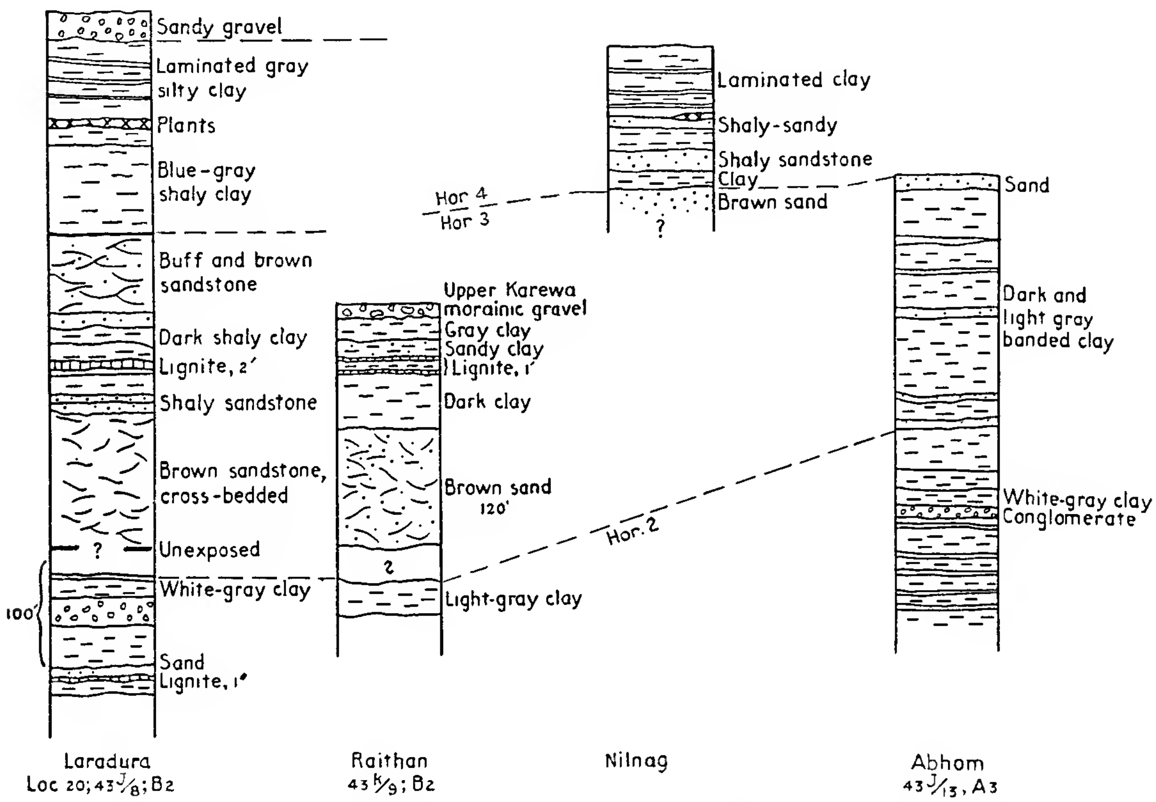


FIGURE 73.—Lower Karewa sequences between Jhelum Valley and Nilnag. Numbers below locality names are those of topographic sheets.

revealed. Near Sangarwein and Abhom this clay gives rise to precipitous cliffs over 400 feet high, and above Hurapur the river has cut vertically into the formation, forming regular canyons.

2. Lower lignite zone: The first thin lignite layer appears at Laradura (fig. 73, locality 20), 50 feet below a well-cemented conglomerate which makes a clear indicator in synclines in the form of thin beds ranging from 1 inch to 3 feet in thickness. Middlemiss (1924, p. 246) described this lower lignite southwest of Raithan, where the thickest bed measures 2 feet 6 inches. It occurs here within a sequence of clay and thinner lignite seams. At Laradura, near Baramula, a thin lignite layer (see report of Krynine on sample K 53) is overlain by 8 feet of brown

sand and 40 feet of dark clay with a 22-foot conglomerate resting on top. Corresponding to this horizon, we find in another section at Abhom, northwest of Shupiyan, 300 feet of dark- and light-gray laminated clays with sand intercalated (fig. 73, Abhom). Comparison of the two sections makes it clear that the incomplete sequence at Laradura can be supplemented by the Abhom section, for both can be correlated by means of the conglomerate. The thickness of this zone would accordingly amount to at least 440 feet.

3. Upper lignite zone: At Laradura and in the Handawor area, the thickest coal measures appear in a series of cross-bedded brown sand overlain by lignite-bearing shaly silt and sands. (See petrologic analysis of specimen 5 by Krynine.) At Laradura (fig. 73) the lower lignite lies several hundred feet below the upper lignite beds, and as these appear above the brown sand, it is possible to trace this horizon by means of this superposition. On the Shaliganga River this brown sand appears under the lignite-bearing clay beds, and at Nichahom, near Handawor, shaly sandstone is exposed in the deepest portions of a similar sequence. At Nichahom and Laradura there are five or six different beds of lignite. Middlemiss (1924, p. 247) cited the following section from a steep scarp about three-quarters of a mile southwest of Nichahom:

	Ft.	*In.*
Sandy bed	5	
Impure lignite	2	
Lignite	6	
Very tough clay	1	8
Lignitic and carbonaceous clay	2	8
Gray sandy, shelly bed	2	6
Carbonaceous clay		10
Lignite	1	10
Blue clay	6	10

Here, as well as at Laradura, brown sand overlies the coal beds. The coal beds, then, are really embedded in a clay-bearing sand, whose cross-bedding leaves little doubt as to the fluvial origin. The close association of river sand with lignite characterizes this series as belonging to a period of heavy delta deposition on the slope of the Pir Panjal. The Karewa Lake, no doubt, was still in existence, as the lignite is found in a bedded clay matrix filled with fresh-water mollusks. The thickness of the lower sand is about 140 feet, that of the lignite-bearing clays is at least 180 feet, and the upper shaly sandstone ranges from 110 to 350 feet. The greatest thickness in this shaly sandstone was found above Nilnag, where the fan character is made evident by forest bedding and gravel content. The total thickness of this zone is therefore at its maximum 670 feet.

Stratigraphically this lignite of the upper series (3) appears in lacustrine clays between two fan formations. Structurally it occurs both in synclines and in monoclines, and for this reason, there can be no doubt as to the secondary nature of the coal basins. These are synclines in which lignite-bearing beds have escaped the denudation that preceded the second glaciation. Although small fragments of

lignitized wood débris were occasionally found in the sand, it is surprising that the lignite beds proper should invariably occur in lake clays. The shaly texture of the lignite, its local silt content, and the absence of any well-preserved stems or leaves point to allochthonous origin. The lacustrine association with clay can best be explained by driftwood accumulated in certain subaqueous channels not far from the mountain front. This would account for the specific occurrence of lignite in front of larger valley tracts (Shaliganga, Rimbiara, Vishav) where intercalation of lake beds with fluvial sand could be expected. The origin of the wood débris is to be looked for in the forested hills of the Pir Panjal, because the pollen content,

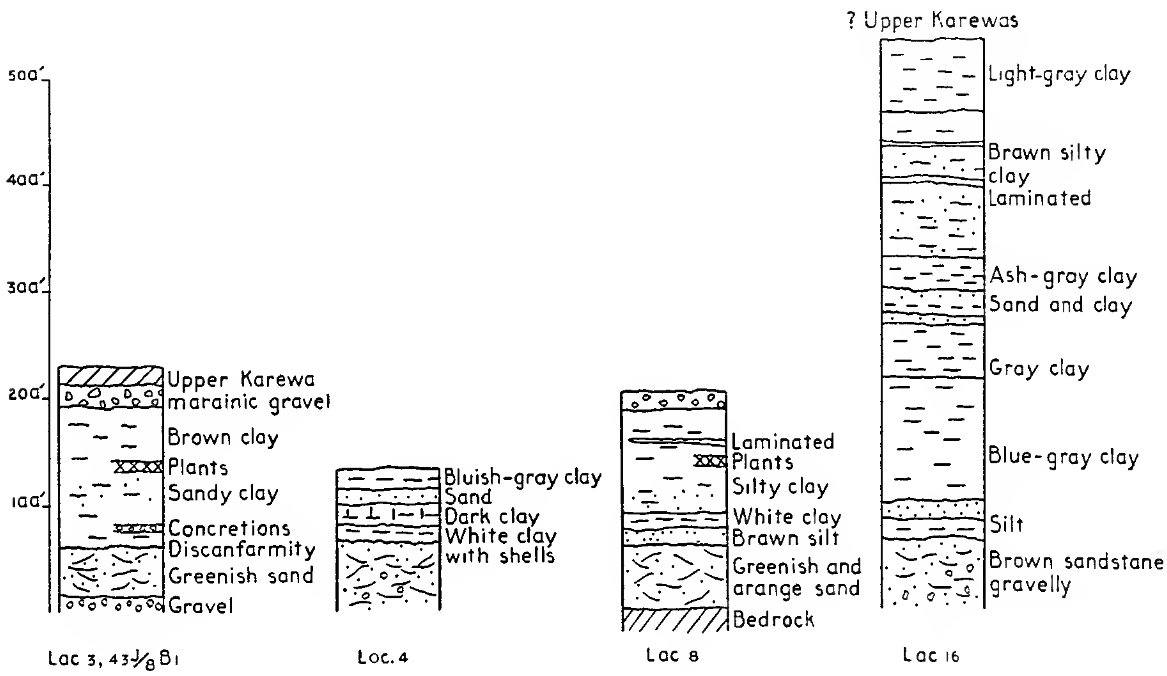


FIGURE 74.—Upper Karewa sequences southeast of Baramula.

as determined by Wodehouse (1935, p. 5), proves a dominance of Coniferae in the flora of the lignite stage. If the driftwood came from the Pir Panjal, the absence of lignite beds on the Himalayan side of the valley is also easily understood. Dainelli (1922) argued differently, saying that the absence of lignite on the Himalayan flank was due to lake currents, initiated by the Himalayan rivers, which drifted wood across the Karewa Lake to the opposite shore. Apart from the improbable existence of such cross currents, it is difficult to see why the lignite should have formed at the front of valley outlets on the opposite side of the Himalayan slope. Another point in favor of our idea is the abundance of plant remains in the clays overlying the lignite beds. The similarity in pollen content (Wodehouse and De Terra, 1935 [1]) between the lignite and the Lower Karewa plant-bearing clays indicates a close relationship between the floras of horizons 3 and 4 during

[1] It should be noted that the samples cited by Wodehouse as Upper Karewas represent Lower Karewa clays and lignites.

Lower Karewa time. As the leaves are well preserved in the clays, it is obvious that they did not drift 8 to 10 miles across the lake but were rather swept into littoral waters from a near-by shore.

Locally, lignite is used as fuel by the villagers. The content of fixed carbon (Middlemiss, 1924) is 27 percent and quite sufficient to guarantee profitable mining under existing commercial conditions.

4. Upper clay zone: Near Baramula (figs. 74, locality 16, and 73, locality 20) the brown gravelly sand or sandstone of the upper portion of the lignite series is overlain by about 450 feet of blue-gray and light-gray clays. This sediment is generally laminated and interspersed with silt and sandy layers up to a thickness of 10 feet (pl. XV, 1). It is at this horizon that the best fossil-leaf beds are found. At Laradura a rich plant locality was found on an escarpment 400 yards east of the hamlet. The leaves are embedded in a tough laminated clay which, upon drying, becomes shaly and brittle; the perfect preservation of nervature and the delicate bedding of the vegetable matter indicate deposition in very quiet water. The altitude of this plant bed is 6,280 feet.

A second locality lies at 9,800 feet in the upper Ningle Valley near Bota Pathri, a little more than 4 miles southwest of Laradura. Plate XIV, 1, shows the tilted position of the clays and the uncomformable contact with a boulder gravel of morainic origin. A set of varves can be seen in the dark plant clay of the lowest exposure. Here the clay contains both plant and fish remains. The varves are exceedingly thin (1/10 to 1/5 of an inch). The winter layers consist of dark colloidal clay, and the summer layers are either of silt or of fine ocherous sand. The exposures have suffered considerably from slumping (due to repeated rainfalls), and an accurate measurement of the varves could therefore not be attained. That these plant beds belong to the same horizon as those in the Laradura locality is suggested by their relation to the older lignite beds. These crop out 200 yards southwest of locality 23, in a stream bed which shows lignite shale overlain by light-gray sand and clays. This sequence dips 30° NE. and is, like the others, covered by first glacial outwash.

A third locality at which plant beds are exposed is found on the escarpment above Nilnag, some 300 yards north of the village of Gogajipathar. Just as at Laradura, the clay beds (about 300 feet thick) are here underlain by brown sand with limonitic concretions, evidently representing the top sand of the upper lignite series. The clay is here more silty than in other sections, and there is also a greater abundance of sandy shale. The series dips 10° NE. and is deeply dissected, so that exposures are numerous in the adjoining forest region. Owing to the fold structure and the sporadic distribution of exposures, it is often impossible to allocate a certain clay or shale to one of the zones above mentioned. Nevertheless, the dominance of brown sand with overlying clay reveals that in this region the higher slopes are entirely built of zones 3 and 4.

As one proceeds from Nilnag across Yus Maidan to Fras Nag (9,300 feet), following the headwater course of the Dudhganga River, these Karewa beds are seen to crop out at many places. The highest level at which they were observed

in this stream bed is at 8,600 feet. From here on, dense underbrush and morainic gravel cover the lake beds. But it is uncertain whether they existed at all or whether they had been denuded. The latter alternative is more likely, as the relief in this region displays a conspicuous drop of 1,300 feet over a distance of 1½ miles, from the plateau level at Liddarmarg down to the river junction below Fras Nag. This steep break may account for the denudation of the lake beds. As soon as this slope is climbed and the planed surface at Liddarmarg is reached, plant-bearing clays reappear. They are exposed west of the shepherd huts in a small stream bed, where they directly overlie the Triassic bedrock. Other outcrops are found in neighboring gullies, and in all of these pure gray clay rests on the undulating relief of the rock floor. The highest exposure was found at an altitude of 10,900 feet, but there is reason to believe that the plant beds originally extended even a few hundred feet farther upstream. Middlemiss (1910, p. 121) described these outcrops and noted a small dip conformable with the inclination of the valley floors. Here, the thickness of the lake clay may not amount to more than 30 feet. The absence of coarse shore deposits in these sections suggests, not only that these plant beds overlap the older zone toward the higher mountain flank, but that inundation was very gradual and sedimentation relatively undisturbed. Also the area could not have been glaciated at that time for the clay is devoid of varves or other glacial features and its fossil flora is decidedly that of a mild temperate climate. This problem, which was commented upon by Middlemiss (1910, p. 122), is discussed in the following section.

To all appearances, plant beds at one time covered the entire slope of the elevated plateau levels between the Tosh Maidan and the Rimbiara Valley tract.

5. Upper sand and gravel zone: The topmost zone of the Lower Karewa series is very imperfectly known, and for this reason it is difficult to decide whether the brown sandstones and sandy gravels of the Laradura and Nilnag sections (fig. 73) really belong to this stage or not. Near Handawor plant-bearing silty clays are overlain by loose gravel and brown sand over 100 feet thick. This series seems to merge into coarse boulder gravel which somewhat resembles the Upper Karewa gravel. In most sections this series disconformably overlies plant beds, but at some places, as near Sedau, gravelly sand of brown or pinkish color conformably succeeds the clay group of the fourth stage. In fact, the locality near Sedau is, to our knowledge, the only one where tilted fan deposits are known to overlie Lower Karewa plant beds. Their thickness may easily amount to several hundred feet. That these pink gravels cannot belong to the second glacial outwash gravels (early Upper Karewa) is evident from their conformable superposition and also from their different coloring and texture. Quite obviously, fan deposition concluded the history of Lower Karewa time. (See Paterson's report on the Liddar Valley.)

Conclusions.—In conclusion we must state that the combined thickness of the Lower Karewa series amounts to approximately 2,160 feet. Considering that this pile of sediment was accumulated in one interglacial period, we ask ourselves

how it was that an inland lake should have produced so impressive a record. Several factors may account for it. Structurally, the lake basin was, and presumably still is, endowed with sinking tendencies (De Terra, 1935, fig. 21). Situated between two rising mountain walls, the Himalayan Range and the Pir Panjal, it subsided like a syncline between two anticlines. The tendency to continuous or intermittent uplifts of the surrounding ranges, which was discussed above, continued throughout the Pleistocene epoch, as is proved by a host of physiographic and geologic observations. The sinking of the valley led to continuous sedimentation with pari passu subsidence of the lake floor. This made for constant denudation of the basin flanks, from which fine and coarse sediments were swept toward the lake. This process may have proceeded in cycles; at one time fans were built and at another clay was laid down, according to whether the rivers were in a state of cutting or filling. The great supply of fine morainic material which the glaciers of the first ice advance doubtless left on the Himalayan slope may have provided part of the vast amount of clay and silt that was precipitated in the lake. (See Krynine's report on samples M 31 and K 25.) Rain wash, no doubt, was more intense than it is now, for the monsoon barrier in the south was several thousand feet lower than at present (p. 123), thus providing for ample and torrential rainfall within the lake region. This ability of the monsoon to penetrate to the slope of the main Himalayan Range must also have led to several winter snowfalls, which even interglacial conditions would have permitted. For all we know, glaciers may still have occupied the higher valleys, and colloidal matter was thus constantly supplied by snow waters. The fine lamination in some of the clays strongly suggests that conditions promoting the seasonal supply of clay and silt actually existed. The monsoon doubtless brought about precipitation of suspended dust, which, as has previously been mentioned, is to be reckoned as a factor of pluvial sedimentation. As the mountains were forested, humus substances provided temporarily for mature soil profiles and thus for clay formation. These climatic, geologic, and geographic factors combined make it fairly understandable why the first interglacial period in Kashmir was a time of excessive lake sedimentation. As compared with the thousands of feet of silt and sand which had accumulated during the equivalent Upper Siwalik stages (Tatrot-Pinjor), our sedimentary record in Kashmir still lags behind the foothill sequences on the southern Pir Panjal flank. (See Paterson on Poonch.) With such considerations in mind there is no reason for assuming an especially prolonged interglacial period.

Reliable data for an absolute time measure of this lake period are unfortunately not available. The reasons are: that the recent Kashmir lakes are not to be considered as relics of the Karewa Lake, and their salt content therefore cannot furnish any information; clay sedimentation was many times interrupted by fan deposition; all the lake beds are folded and exact correlations between laminated or varved deposits are as yet not possible; also sedimentation doubtless was influenced by subsidence of the basin floor. In our opinion such complications do not permit the making of exact geochronologic measurements, and hence we refrain from estimating the length in years of the first interval.

Origin of Karewa Lake

The great Karewa inundation presents a major problem which has engaged the mind of almost every naturalist who has traveled in Kashmir. Even the ancient poets have woven a mythologic tale around this event, which is narrated in the "Chronicle of the Kings of Kashmir." Godwin-Austen (1864, p. 383) and Lydekker (1883, p. 78) agreed that this lake was formed by uplift of the Pir Panjal and that it spilled by overflow, thereby cutting the Jhelum Gorge below Baramula. Oestreich (1906, p. 24) did not discuss the origin of the lake but only the history of the stream course below Baramula, and in doing so he took no account of the existence of the Karewa Lake. Dainelli (1922), on the other hand, stated clearly that the Karewa Lake had its spillway below Baramula and that the damming was only temporary, lasting but a brief span in early Pleistocene time. All previous investigators agree that it was the Jhelum Gorge through which the lake was spilled, but none of them visualized the damming process.

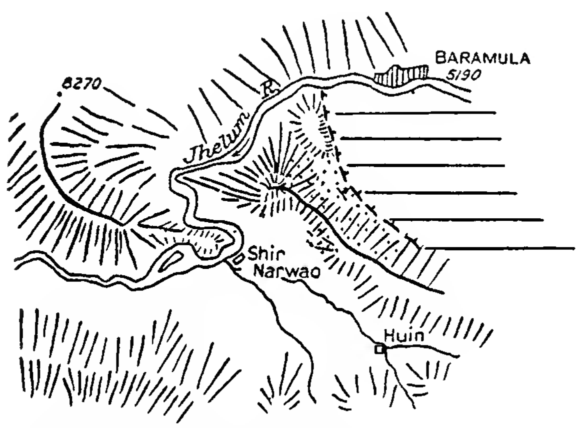


FIGURE 75A.—Sketch map of Jhelum Gorge. Scale, 1 inch to 1 mile. Stippled area, ancient fan faulted against Lower Karewa beds.

In the following statement an attempt is made to explain this event, although it is realized that more detailed data on the Jhelum Valley are required for a clearer conception of the Pleistocene history of the transverse gorge. The key region to the solution of the problem lies between Baramula and Rampur. In this portion the river cuts through a high spur at Shir Narwao, where its course is still deflected (fig. 75A). This spur is part of the ancient divide through which the ancestral Jhelum cut backward, finally to capture the drainage of the Kashmir Basin. On the right bank the beveled top of the spur lies 1,400 feet above the stream; on the left bank, 1,200 feet above. On the left ridge Lower Karewa fan deposits and lake beds rest against bedrock tilted 25° toward the basin and down-faulted in the same direction. The fault strikes northwest and clearly marks a major displacement on the slope of the Pir Panjal. It turns southward near Huin and reappears at Laradura, where turbulent topography testifies to the effects of that great earthquake of 1888 which destroyed not only the town of Baramula but many villages along the mountain slope. In other words, the ancient divide is a fault-line scarp on the Kashmir side, characterized by seismic disturbances. The presence of ancient river deposits on this divide makes one suspect, as it did Oestreich, that the Jhelum flowed at one time across this spur and that it heightened its bed by gradual silting until most of the ancient valley was filled up with sand and gravel. This is the preglacial stage (B, fig. 75B), which followed a long time after the stream capture across

the ancient divide (A, fig. 75B) had taken place. The river was nearly graded when uplift of the Pir Panjal axis set in (C). This uplift must have carried the old divide to such a height that the river was deflected and prevented from pursuing its course. To visualize this event, it should be recalled that the Jhelum gradient was fairly established and that there was no deep transverse gorge such as exists today, which means that a slight initial uplift would have sufficed at first to block the stream and turn it, so to speak, backward to the basin. A landslide may have dislodged the fan deposits on the now steepened slope and helped to bar the stream. After this, flooding of the basin must have been instantaneous, as indeed the sudden change from coarse sandy to clay beds in the Lower Karewa indicates. The lake presumably established its spillway at an early time, but as its channel had been dislodged through uplift it could not cut into its old débris but was forced to flow across a convenient gap in the rocky divide. This retarded the outflow of the lake, the bottom of which undoubtedly subsided farther in adjustment to the Pir Panjal uplift. This sinking of the lake basin led in turn to new displacements along the mountain front, and faulting carried the old Jhelum fan to even greater height (D, fig. 75B). The spillway now entrenched itself more vigorously in bedrock, which may have caused a first draining of the Karewa Lake at the end of the first interglacial period. This is the phase of the green-sand deposition along the Himalayan slope and of the upper lignite-bearing sandy beds on the Pir Panjal side. The lake was at a low level and considerably reduced in size when the second glaciation set in, for few glacial-lake sediments are recorded in the basin. The Lower Karewa beds were already tilted (D, fig. 75B), and the spillway was unquestionably firmly established in bedrock, but from now on the existence of the lake was no longer so dependent on the ratio of uplift to erosion but rather on lowering of the spillway and water supply in the basin. The relative scarcity of glacial-lake deposits indicates that during the second glacial period inflow slackened and the spillway presumably remained stationary. At the beginning of the following interglacial period, however, the lake deepened again, and it must for a time have been pretty well sealed off, as the sediments prove (marl-bearing beds). Once more uplift temporarily interrupted the outflow, and in this process subsidence of the lake floor, which caused lowering of the lake level, must have played a dominant part. Presumably this deepening of the lake was short-lived, because not only the rainfall decreased but the amount of ice in

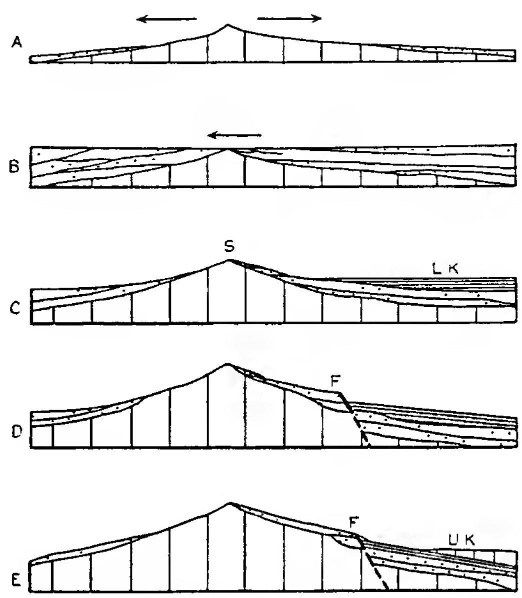


FIGURE 75B.—Suggested development of ancient divide. L.K., Lower Karewa beds; U.K., Upper Karewa beds; F, fault; S, spillway established.

the valleys as well. Once the lake had regained the spillway it emptied quickly, and with continued uplift the new Jhelum Valley deepened, thus leading to complete spilling of the lake. We do not believe that this event caused a much greater inundation in the plains than the large Indus floods made in historic time (see part II), because of the absence of such geologic records and because of the progressive shrinkage of water supply in the Kashmir Basin.

The Karewa Flora and Its Bearing on Climatic and Paleogeographic Changes

The following list of plants, leaves, and fruits (from zone 4 of the Lower Karewa lake beds) was compiled from collections made by Dr. R. R. Stewart and me (pls. LIII, LIV). Detailed description and illustration of this flora will be presented at a later date by Dr. Stewart. For the moment the following list of plants is given:

WOODY PLANTS

Ranunculaceae:
- Clematis montana Buch.-Ham., winged fruit.

Berberidaceae:
- Berberis ceratophylla G. Don, leaves.

Aceraceae:
- Acer caesium Wall. ex Brandis, samara and leaf fragment.
- Acer n. sp.? near acuminatum Wall., part of leaf.
- Acer pentapomicum Stewart?, leaf fragment.

Hippocastanaceae:
- Aesculus indica Colebr., parts of leaves.

Sabiaceae:
- Meliosma pungens Walp.??, leaf fragments.

Papilionaceae:
- Indigofera hebepetala Benth.?, leaflets.

Rhamnaceae:
- Rhamnus purpurea Edgew.?, leaf fragments.

Rosaceae:
- Prunus jacquemontii Hook. vel. aff., leaves.
- Prunus cornuta Wall., leaf fragments.
- Prunus cerasifera Ehr. vel aff., leaves.
- Spiraea canescens D. Don?, leaves.
- Rosa webbiana Wall., leaves, very small, appr. R. beggeriana Schrank.
- Rosa macrophylla Lindl., leaves.
- Pyrus communis L. vel aff., leaf.
- Pyrus foliolosa Wall. vel aff., leaflets.
- Pyrus aucuparia Gaertn. vel aff., leaflets.
- Pyrus pashia Buch.-Ham.?, leaves.
- Cotoneaster microphylla Wall., leaves.
- Cotoneaster nummularia Fisch. et Meyer, leaves.
- Cotoneaster bacillaris Wall., leaves.

Araliaceae:
- Hedera helix L., fruit.

Cornaceae:
Cornus macrophylla Wall.?, leaf fragments.

Caprifoliaceae:
Viburnum stellulatum Wall. vel aff., leaf.

Oleaceae:
Fraxinus excelsior L., winged fruits.

Cupuliferae:
Alnus nitida Endl., leaves and fruit.
Alnus sp., fruits, smaller.
Carpinus?, leaves.
Betula utilis D. Don, fruit and leaves.
Betula sp., leaves.
Quercus incana Roxb., many specimens (leaves).
Quercus semecarpifolia Smith, many leaves.
Quercus ilex L., many leaves.
Quercus dilatata Lindl., many leaves.
Quercus glauca Thunb., leaves.
Castanopsis?, leaf fragments.

Juglandaceae:
Juglans regia L., two leaflets.

Ulmaceae:
Ulmus wallichiana Planch., leaves.
Ulmus parvifolia Jacq., leaves.

Salicaceae:
Salix wallichiana Anders., leaves.
Salix denticulata Anders., leaves.
Salix, two or three unidentified sp.
Populus alba L.?, leaf fragment.
Populus nigra L. vel aff., leaves.
Populus ciliata Wall.?, leaf fragments.

Coniferae:
Pinus excelsa Wall., fragments of needles.
Abies webbiana Lindl., winged seeds.
Picea smithiana Boiss., winged seed.
Juniperus, leaf and crushed fruit?
Taxus?, leaf.

HERBACEOUS PLANTS

Nymphaeaceae:
Nelumbium speciosum Willd., leaf fragment.

Hydrocaryaceae:
Trapa natans L., fruits.

Typhaceae:
Typha?, pieces of leaves.

FERNS

Adiantum pinnule; differs from anything found now in Kashmir.

Dryopteris, near filix-mas (L.) Schott, pinnules.

Selaginella?

The following genera were identified from pollen only (Wodehouse and De Terra, 1935, p. 5):

Picea sp.	Alnus sp.
Abies sp.	Juglans sp.
Ephedra sp.	Persicaria sp.
Gramineae gen. indet.	Chenopodiaceae gen. indet.
Carpinus? sp.	Artemisia sp.

In addition, Middlemiss (1910, p. 122) listed *Cinnamomum? tamala* and possibly *Jasminum*.

Diatomaceous beds in the Karewas.—The lignite-bearing beds at Handawor and in the Shaliganga Valley yielded some interesting data on microscopic life in the Karewa Lake. Paul S. Conger, of the Carnegie Institution of Washington, listed the following forms. In this list F stands for frequent, C for common, S for scarce, VS for very scarce, and VC for very common. The asterisk (*) indicates species not listed by Lundquist in this region.

Sample K 30. Kashmir (Karewa), India. Fresh-water clay belonging to Lower Karewa beds (first interglacial). Much lime. Diatoms present, but all badly broken.

Amphora ovalis var. lybica (Ehr.) Cl.	S
Cymatopleura elliptica W. Sm.	S
Cymbella ehrenbergii Ktz.	C
Cymbella lanceolata (Ehr.) V. H.	C
Epithemia argus Ktz.	C
Epithemia zebra (Ehr.) Ktz.	C
Navicula ambigua Ehr. (craticular form)	S
Navicula amphirhynchus Ehr.	S
Navicula cuspidata Ktz.	S
Navicula viridis (Nitzsch) Ktz.	F
Rhopalodia gibba (Ehr.) O. Müll.	F
Stauroneis phoenicenteron Ehr.	VC
Synedra ulna (Nitzsch) Ehr.	S

(Cymbella ehrenbergii and the Epithemias dominate this sample.)

Sample. Handawor (Lower Karewa beds), India. Fresh water. Very soft dark-gray shale, peaty, containing numerous very minute snail shells. Much lime. Many, and a great variety of diatoms:

Amphipleura pellucida Ktz.	*VS
Amphora ovalis Ktz.	F
Amphora ovalis Ktz. var. lybica (Ehr.) Cl.	F
Amphora ovalis Ktz. var. pediculus Ktz.	S
Cocconeis placentula Ehr. (and varieties)	VC
Cyclotella comta (Ehr.) Ktz.	VC
Cymatopleura elliptica W. Sm.	VS
Cymatopleura solea (Breb.) W. Sm.	VC
Cymbella cesatii (Rabh.) Grun.	*S
Cymbella cistula (Hemp.) Kirchn.	C

Cymbella ehrenbergii Ktz.	VC
Cymbella lanceolata (Ehr.) V. H.	F
Cymbella prostrata (Berk.) Cl.	*S
Cymbella turgida (Greg.) Cl.	*S
Cymbella ventricosa Ktz.	F
Epithemia argus Ktz.	VC
Epithemia sorex Ktz.	C
Epithemia turgida (Ehr.) Ktz.	C
Epithemia zebra (Ehr.) Ktz.	C
Epithemia zebra (Ehr.) Ktz. var. porcellus (Ktz.) Grun.	C
Fragilaria capucina Desm.	F
Fragilaria construens (Ehr.) Grun.	S
Gomphonema capitatum Ehr.	*S
Gomphonema constrictum Ehr.	F
Gomphonema geminatum Ag. var. hybrida Grun.	*S
Gomphonema intricatum Ktz.	C
Gomphonema lanceolatum Ehr.	C
Navicula amphisbaena Bory	F
Navicula bacilliformis Grun.	VS
Navicula borealis Ehr.	VS
Navicula (Pinnularia) brebissonii Ktz.	F
Navicula cuspidata Ktz.	F
Navicula (Neidium) iridis Ehr.	*S
Navicula (Neidium) kozlowi Meresch	*S
Navicula limosa Ktz.	*S
Navicula major Grun. var.	F
Navicula oblonga Ktz.	VC
Navicula polygramma Ehr.	VC
Navicula radiosa Ktz.	VC
Navicula sphaerophora Ktz.	*VC
Navicula viridis (Nitzsch) Ktz.	F
Nitzschia angustata (W. Sm.) Grun.	F
Nitzschia hungarica Grun.	C
Nitzschia palea (Ktz.) W. Sm.	S
Nitzschia sigmoidea (Ehr.) W. Sm.	C
Pleurosigma attenuatum Ktz.	VS
Pleurosigma kützingii Grun.	VS
Rhoicosphenia curvata (Ktz.) Grun.	VC
Rhopalodia gibba (Ehr.) O. Müll.	C
Rhopalodia gibba (Ehr.) O. Müll. var. ventricosa (Ehr.) Grun.	VS
Stauroneis anceps Ehr.	S
Stauroneis phoenicenteron Ehr.	S
Stephanodiscus astraea (Ehr.) Grun.	VS
Surirella bifrons Ktz.	*VC
Synedra capitata Ehr.	S
Synedra gaillonii (Bory) Ehr.	S
Synedra obtusa W. Sm.	S
Synedra pulchella Ktz.	VC
Synedra ulna (Nitzsch) Ehr.	S
Synedra ulna (Nitzsch) Ehr. var. danica (Ktz.) Grun.	S
Synedra vitrea Ktz.	*S

Sample K 17. Kashmir (Karewa), India. Medium hard, dark-gray shale. Many minute snail shells. Much lime. Diatoms abundant, many broken.

Cocconeis placentula Ehr.	S
Cymatopleura solea (Breb.) W. Sm.	S
Cymbella ehrenbergii Ktz.	F
Cymbella lanceolata (Ehr.) V. H.	S
Cymbella ventricosa Ktz.	S
Epithemia argus Ktz.	F
Epithemia zebra (Ehr.) Ktz.	F
Gomphonema intricatum Ktz.	S
Navicula viridis (Nitzsch) Ktz.	S
Stauroneis phoenicenteron Ehr.	S

Mr. Conger comments as follows:

The above sample from Handawor is the richest of all sent to me, and represents probably a rather sizable, moderately shallow, somewhat alkaline or hard-water lake in which diatoms flourished in great profusion, as well as very likely did other forms of life. At the time this sample was laid down the lake was perhaps in the very height of its productivity. The sample is greatly dominated by the diatoms, but not quite rich enough for a diatomaceous earth.

The Karewa flora analyzed.—All the plants listed above, some of which are shown on plates LIII and LIV, with the exception of oak, cinnamon, and a few species (as yet undetermined) of maple, hazel, birch, and willow, figure prominently in the recent flora of the northern Pir Panjal. Considering the great antiquity of the Lower Karewa plant beds, this close resemblance to the recent flora is startling indeed. A critical examination of the facts and premises leading to this conclusion may provide a reasonable explanation. In the first place it must be stated that the botanic analysis rests mainly on identifications of leaves, and this introduces a considerable range of errors so far as species determinations are concerned. Leaves of *Rosa* and *Spiraea* and of the order Salicaceae resemble each other so closely that in the absence of flowers and fruits specific identifications must remain arbitrary. In other words, the botanist in charge of the work could not detect such forms as might have been archaic and different from the living species, and hence we are unable to recognize the truly foreign elements in this plant association.[1] Another consideration is that the fossil plants were found only on the Kashmir slope of the Pir Panjal, which leaves us entirely in the dark so far as the floras of the Kashmir Valley and of the Himalayan slope are concerned. The fact that the fossil leaves reflect a plant world such as now flourishes at lower altitudes (around 6,000 feet), together with the geologic consideration of subsequent mountain uplifts, makes it probable that this lowland flora actually contained foreign elements which are unrecorded or unrecognized in the lake beds. These beds obviously received vegetable matter only in the littoral regions, which accounts for the general uniformity of the flora. This fact also reminds us of the highly selected character of this fossil-plant association.

The different aspect of the relief, especially the lower altitude of the monsoon barrier, no doubt promoted the northern advance of forms which are now either re-

[1] Dr. Stewart has meanwhile found several other species not represented in present-day Kashmir.

stricted to the southern monsoon slope (cinnamon, oak) or unrecorded in the plant beds. To speak, therefore, of a close identity between the recent and early Pleistocene flora is correct only so far as the general generic association is concerned, and even then our assumption is based on premises which by virtue of the geologic selection of plant records are incomplete.

However critical our considerations may be, there is no denying the fact that the recent and the first interglacial floras closely resemble each other. The strangeness of this resemblance appears less formidable if we recall that the interglacial floras of the Alps also are closely related to the present flora. This is true for the interglacial forest flora of the Alps (Penck and Brückner, 1909, p. 1158). Penck also stated that ecologically only vertical shifts of plant zones took place, whereas the principal geographic division into a southern (Illyrian) and a northern (Baltic) division was at that time clearly established.

As the percentage of extinct species in the Karewa flora is unknown, there is no object in discussing this matter further until additional data are available. However recent its aspect is, there can be no doubt as to the profound contrast offered between the present position of the plant beds and the ecology which the Karewa flora implies.

In order to elucidate this problem the following questions demand answers: (1) In what specific way does the Karewa flora differ from the present flora? (2) What climatic changes do these differences imply? (3) What relationship, if any, exists between these changes and geologic conditions?

Previously (p. 16) we have noted that the Kashmir slope of the Pir Panjal displays a zonal arrangement of plants. In none of these do oak and cinnamon appear, in striking contrast to the Karewa flora, where oak is one of the forms most commonly represented. The oak-pine forest so characteristic of the present southern monsoon slope of the Pir Panjal does not now cross the watershed, and here its uppermost limit is 8,000 feet above sea level. As we know that this oak-pine forest typifies the monsoon flora of the southern slope, it obviously must have once extended into the Kashmir Valley. The same is true of the distribution of cinnamon, which at present grows a few hundred miles southeast from Murree, in the monsoon-swept area of the Simla Hills. This means that during the first interglacial time the climate in the Kashmir Valley differed from that of today; it was more moist and slightly warmer.

The climatic change which this feature implies is obviously connected with a wider range of the monsoon influence during the first interglacial period. If the monsoon were at present permitted to precipitate its summer rains in full force over the valley and the Himalayan slope, the pine-oak forest would undoubtedly spread across the Pir Panjal and thus invade the valley. It is the present altitude of the fore range which makes such an advance impossible. Hence it is our contention that in Karewa time the Pir Panjal was of lesser height than now—a conclusion fully supported by structural and morphologic evidence. Good evidence for the uplift of the plant-bearing lake clays is presented in the exposures of the upper Ningle Valley near Gulmarg (pls. XIV, 1, and LV).

The high position of the plant beds, more than 3,000 feet above the Laradura locality, raises problems of great geologic significance. Two possible explanations present themselves. The beds were laid down either in an ice-dammed pond or in a lagoon of the great Karewa Lake. The former supposition would obviously not demand special mountain uplift but it would require that the fossil leaves represent a highland flora. Unfortunately, the botanical aspect is here not as clear as might be wished. The predominance of willow, birch, beech, poplar, rose, and elm and the absence of oak indicate a flora such as nowadays ranges from an altitude of 5,000 to 8,000 feet in Kashmir. On the other hand, the presence of lotus (*Nelumbium*), a genus commonly found on the Kashmir lakes at 5,200 feet, restricts the range of altitude for the fossil flora to less than 6,000 feet. The absence of oak and the greater variety of small-leafed trees, as compared with the flora from Laradura and Nilnag, might indeed suggest that the Ningle Valley flora grew in a slightly colder temperature. However, this deduction cannot be upheld in view of the abundance of oak, hazel, and rose leaves in the plant beds found at 10,300 feet at Liddarmarg (Middlemiss, 1924). This indicates that the Lower Karewa flora found at such altitudes does not match with the present flora of the alpine zone (p. 16) but that it corresponds to a floristic zone which now ranges from 5,000 to 7,000 feet above sea level. Wodehouse (1935, p. 18), in his pollen analysis of the Karewa plant beds, concludes that the climatic conditions under which the Karewa deposits were laid down were essentially the same as those found at Lake Manasbal (5,180 feet) at the present time. This corroborates our contention that the leaf beds formed at considerably lower altitudes. The excellent preservation of the leaves excludes the possibility of their having been swept down by streams for several miles from higher regions. Hence the present altitude of these plant beds can be due only to uplift of the Pir Panjal range. Direct proof for this uplift is found in the tilted and folded position of the lake clays, which is discussed farther on.

Hence our conclusion that the present position of the lake beds affords direct evidence for the young mountain uplift of the Pir Panjal, which caused vertical shifting of plant zones as well as a southward migration of the monsoon forest. The underlying tectonic principles of this uplift are discussed on subsequent pages.

Land and Fresh-Water Fossils of Karewa Age

Apart from the elephant remains of Sombur there were collected from the same bone bed of first interglacial age a number of indeterminate bones of artiodactyl mammals and of birds. From sandy beds of Lower Karewa age near Badgom Mr. Aiyengar obtained an antler fragment of *Cervus* sp.

The fish remains found at Sombur and in the upper Ningle Valley belong to either *Schizothorax* or *Oreinnus* (Hora, 1937), genera which at present are numerous in the lower streams of Kashmir.

Of invertebrate fossils a great many fresh-water and a few land mollusks were collected at various horizons in the Lower and Upper Karewa beds. The Lower Karewa beds are especially rich in shells, which occur most abundantly in

the gray clay layers but also in shaly sands of the lignitic beds. Although the material has not yet been fully studied, it is nevertheless possible to assign most of the fossils to a few genera, some of which were previously described from other collections by Prashad (1925). He listed the following forms from a Lower Karewa horizon:

Bensonia sp.	Corbicula sp.
Bithynia tentaculata var. kashmirensis Nev.	Lamellidens sp.
Gyraulus cf. pankongensis (Neville) v. Mart.	Planorbis sp.

Bithynia, *Gyraulus*, and *Planorbis* are at present found in Kashmir in association with palearctic forms,[1] but that does not necessarily mean that the fresh-water fauna of Lower Karewa time was of the same type. No definite conclusions can be drawn from the small collection described by Prashad, but Mr. Conger in commenting on the diatoms [2] assures me that the forms listed from Handawor indicate a mild temperate climate.

In a collection of shells made by Professor Hutchinson and me, Dr. Prashad determined from Upper Karewa beds the following forms:

Valvata piscinalis (O. F. Müller).
Lymnaea auricularia (Limn.).
Pisidium hydaspicola (Theobald).
Planorbis planorbis var. tangitarensis (Gérm.).
Gyraulus cf. pankongensis (Neville) v. Mart.

All of these except the *Gyraulus* are still living near the fossil localities, but according to Prashad *Gyraulus* possibly belongs to another species now living in Kashmir.

Mountain Uplift and Resulting Structures in the Lower Karewa Beds

Previous investigators, particularly Middlemiss (1910, p. 136), who had commented upon an apparent connection between the uplift of the Pir Panjal and the folded structure in the Karewa beds, had held that this uplift was the direct cause of the folding of the Pleistocene. Dainelli (1922) had even attempted to show that the intensity of folding, as displayed by the dip of the Karewa beds, grew in proportion with the altitude of the range. This contention is of considerable interest to all those who, like me, have of late demonstrated that relief features of the Himalaya and neighboring ranges bear witness to young mountain movements. So far it had not been possible to date this late diastrophism and it was even unknown what share the Pleistocene epoch had taken in these young crustal deformations. This lack of detailed information obviously was due to our incomplete knowledge of the structure and stratigraphy of the Karewa and Siwalik formations. As long as the Siwalik beds were considered a conformable unit it was difficult, if not impossible, to recognize the mountain-making phases which had otherwise already been deduced from geomorphologic data. Only recently

[1] According to a manuscript by Dr. Prashad on "Aquatic and amphibious mollusks from Kashmir," collected by Professor Hutchinson on my first expedition.

[2] By letter to me.

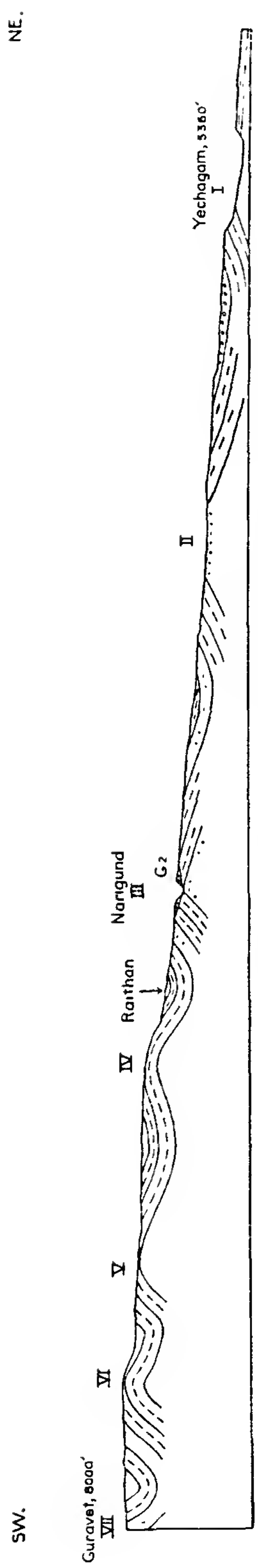


FIGURE 76.—Cross section through Shaliganga Valley. I, II, III, etc., anticlines; G2, second glacial gravel.

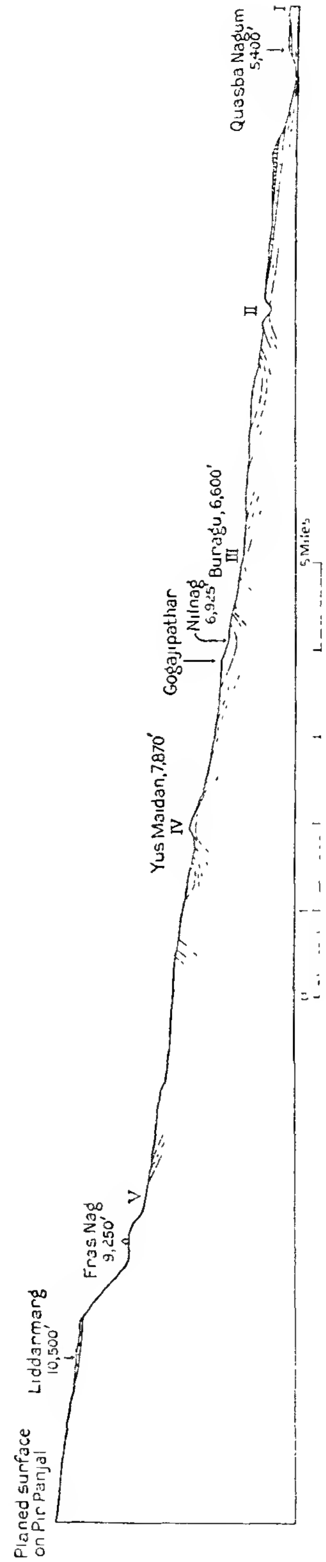


FIGURE 77.—Cross section through folded Karewa beds, Nagum to Liddarmarg. I, II, etc., anticlines.

Teilhard and I (1936) showed that at least three infra-Pleistocene movements were recorded in the Upper Siwalik and younger beds, the most striking of which had been documented by an angular unconformity between the Boulder conglomerate and the underlying Tatrot-Pinjor beds. It is true that both Middlemiss and Lydekker had recognized the unconformable contact between Lower and Upper Karewa beds, but as these series had not been dated the nature and age of their folding remained obscure.

It is, indeed, fortunate that the Kashmir Valley, being an intermontane basin made up of thick Pleistocene beds, affords insight into the structural records left during the Pleistocene mountain uplifts. As this basin has witnessed repeated glacial advances and interglacial stages, an opportunity is given to study the relations of mountain uplift to the glacial cycle. In view of the fact that this uplift of the Himalayan structure passed through various stages, it is expedient to describe the Pleistocene phases in their time order, beginning with the first interglacial stage.

Mention has already been made of the repeated formation of fans prior and subsequent to the Karewa Lake formation, and it has been suspected that their appearance reflected the growth of the Pir Panjal. From the occurrence of coarse fan deposits in the slope regions of the Lower Karewa series, one might easily get the impression that this shedding of rock waste had never quite ceased during the first interglacial lake period. This process was, in our opinion, connected with the rejuvenation of drainage in the Pir Panjal. Whereas climatic conditions at that stage were similar to (though more humid than) those found now, it is obvious that erosion was powerful and the reaction of rivers to uplift must have been immediate. Uplift and erosion preceded the lake period and continued, apparently, into this interglacial period until a time when a paroxysm of uplift broke the more quiet continuity of relief making and of basin sedimentation. This paroxysm was recorded in the form of an angular unconformity between the Lower Karewa beds and the overlying Karewa gravel (second glacial), leaving a faulted fold structure in these lake beds. By surveying the Karewa structure it has now become possible to analyze the relationship between uplift and folding, as postulated by Middlemiss and Dainelli.

In discussing the tectonics of the Lower Karewa beds we concentrate on the better-known profiles, which are illustrated in figures 76 and 77. The most complete section is exposed along the Shaliganga River (fig. 76). Two miles southeast of Badgom the first shallow syncline is exposed in lake beds which at Yechagam dip 10° SW. On the slope opposite this village the strata dip 7° NE. The small river at Yechagam, which is a tributary of the Shaliganga, thus flows on an anticline, which reappears three-quarters of a mile northeast of Nagum (fig. 77). The structure is covered by Upper Karewa loessic beds, which apparently take part in the tilting. Three miles upstream a second anticline, which is unconformably overlain by terrace gravel, appears. The gravel continues along the river and appears near Narigund as a coarse boulder gravel above the crest of the third anticline. The following syncline at Raithan contains the upper lignite beds, which are denuded from the adjoining fourth anticline. Toward Guravet-Kalan the lake beds

dip 10° NE. as far as the fifth anticline, the crest of which is exposed near the point marked "P. 7190" on map 43 K/9, section B2. Significantly enough the dip is considerably steeper here, being 50° at places, but it flattens out again to 8° on the northeast limb of the next anticline (the sixth). The folding is here very close but could not be followed farther upstream because of a lack of exposures.

The section shown in figure 77 is 17 miles long and leads from the border of the valley near Nagum across Nilnag and Yus Maidan to the high plateau surface of the Pir Panjal. The first anticline is exposed three-quarters of a mile northeast of Nagum, where the shallowness of the folding once more becomes apparent. The syncline northeast of Buragu contains lignite beds which possibly belong to the deeper horizon. Above Nilnag the brown sandstones and silt beds of zones 3 and 4 build the forested slopes, in which exposures become increasingly sparse. Southwest of Yus Maidan only two outcrops were located within a distance of 3 miles. This explains why in figure 77 only five anticlines are represented.

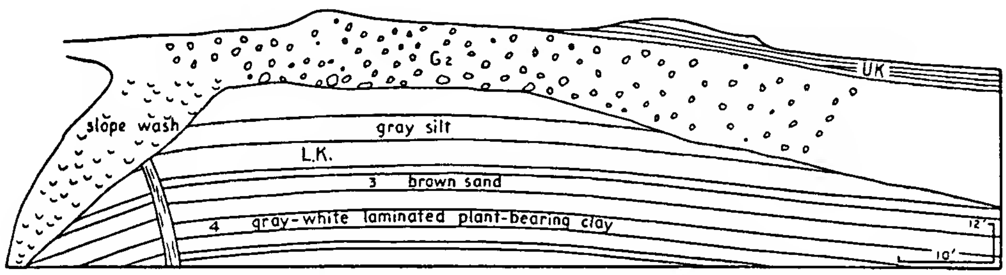


FIGURE 78.—Anticline in Lower Karewa lake beds overlain by second glacial outwash (G2) near Shupiyan. (See pl. XVI.) U.K., Upper Karewa beds; L.K., Lower Karewa beds; 3, 4, zones in the Lower Karewas.

At the outlets of the Rimbiara and Vishav rivers few outcrops of Lower Karewa beds are of sufficient height to demonstrate this fold structure clearly. Very significant, however, is one exposure which shows a faulted anticline in Lower Karewa beds unconformably overlain by glaciofluvial outwash gravel of the second glaciation (fig. 78 and pl. XVI). This section is exposed on the left bank of the Rimbiara about 200 furlongs south of Balapur and 2 miles north of Shupiyan. The laminated clay in the lower portion of the section belongs probably to the topmost Lower Karewa beds, as it contains plants and fresh-water mollusks. The anticline is slightly faulted and underwent erosion before the Karewa gravel was laid down. This gravel is here 22 feet thick and is overlain by Upper Karewa loessic silt and clay slightly tilted toward the northeast. Another exposure of folded Lower Karewa beds was observed on the left bank of the Rimbiara opposite Hurapur. Here the lake beds form a narrow syncline which is down-faulted on the limb of the adjoining western anticline. Boulder gravel, 200 feet thick, overlies these folds and, like the Karewa silts above, is apparently slightly tilted downstream, though nowhere folded (fig. 90, pl. XIV, 2).

In the adjoining Vishav Valley (fig. 86) Lower Karewa beds and fan deposits are folded and faulted against the Paleozoic rock floor. The steepness of dip (60°)

at the border fault and the appearance of pre-Karewa gravels clearly indicate a major displacement suggestive of a general down-faulting and sagging tendency in the Pleistocene basin filling. Here also the boulder gravel lies unconformably on the eroded fold structure.

This border fault was also observed at the outlet of the Ningle Valley near Nagbal (fig. 79). Paleozoic slate rock (P) forms a precipitous mountain slope, and against it lie gray clay beds with lignite, but the contact is not clearly visible and therefore has been left blank in the section. About 1,500 feet downstream a synclinal fold is exposed just before the Lower Karewa beds disappear beneath morainic outwash gravels of later glaciation. Faulting has doubtless removed the lower zones and caused the clay beds of zone 2 to rest against the bedrock slope. The total displacement here may therefore amount to almost a thousand feet. How much of this faulting is due to the first interglacial diastrophism or to later movements is difficult to tell, as we must remember that border faulting may have

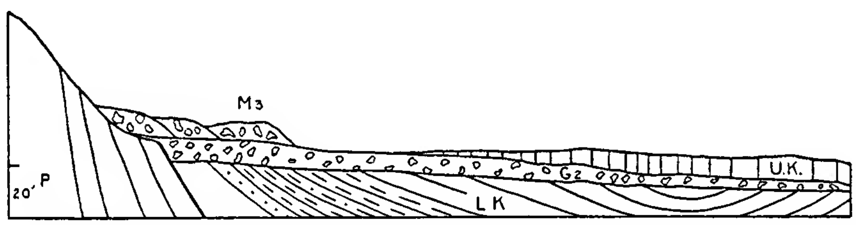


FIGURE 79.—Folded Lower Karewa beds at outlet of Ningle Valley. P, Paleozoic slate; L.K., Lower Karewa beds; G2, second glacial gravel; U.K., Upper Karewa beds; M3, third moraine.

been revived at successive intervals in later times. From the slight tilting (6°) of the overlying boulder gravel, however, it is certain that the major displacement occurred prior to the second glacial period.

Other effects of faulting can be observed as one approaches the Jhelum Valley. At Dangarpur, for instance, the axis of an anticline is exposed half a mile north of the village. Between it and the adjoining mountain slope Karewa clays make a syncline, in the eastern limb of which the lower clay and gravels rest against Paleozoic slates. The contact was not observed, but to all appearances faulting was here less effective than in other regions, as the sequence seems more complete. The dip, however, grows perceptibly in steepness as the mountain border is approached.

These examples must suffice to prove that at the end of the first interglacial period faulting occurred along the mountain slope and folding in the basin. The sections in figures 76 and 77 show that deformation was stronger on the Pir Panjal flank than in the basin, where the folds are reduced to mere undulations. This clearly points to an increase of tangential compression toward the mountain flank. Such a structure excludes the possibility of folding due to slumping or gliding, as in that event one would expect the folds to increase in reverse order toward the basin center. There is also a marked tendency of the dip to steepen in the south-

western limbs of the anticlines, which indicates that pressure of folding was exerted from the Pir Panjal. Evidently a strong paroxysm of uplift released tangential pressure upon the basin filling, which reacted to this movement by folding. When this pressure became so great that a more plastic deformation was no longer possible, the soft clay and gravel beds fractured along the precipitous bedrock slope and were faulted, a process which was presumably promoted by a deeper-seated displacement in the rigid rock structure. This process not only must have left portions of the Lower Karewa beds high in the elevated valley tracts, but it must also have changed the configuration of the lake basin. The basin became narrower, and its Pir Panjal flank rose more steeply than before above the valley floor. This in turn led to quick rejuvenation of the Pir Panjal relief and to deepening of the major valleys. The eroded surface of the anticlines in the basin indicates that erosion was well under way before the boulder gravel of the next glaciation was laid down. Indeed, the extraordinarily strong phenomenon of this second glaciation is unthinkable without preceding erosion and elevation of the Pir Panjal relief. From this discussion we surmise that the structural history of the Pir Panjal flank corresponds closely to that of the Himalayan side. The prominent slope between the first two glacial troughs in the Sind Valley signifies, as Paterson has pointed out, a period of great erosion which we can now correlate with the first interglacial uplifts of Kashmir.

LATER MAJOR GLACIATIONS

General Remarks on Second Glacial Period

The first glaciation in the Pir Panjal was weak, in striking contrast to the corresponding strong glaciation on the Himalayan slope. The second ice advance was, in comparison, so much more effective in this region that one might feel induced to call it the first Pir Panjal glaciation. There is not a single valley in this region in which we do not find at least one kind of evidence for glacier action, such as trough valleys, striated bedrock, moraines, and glaciofluvial outwash deposits. The chief characteristic traces of this second glaciation are wide trough valleys, thick ground moraines, few lateral moraines, and no terminal moraines. Absence of the terminal moraines was also noted on the Himalayan slope (p. 45) and the explanation given for it holds good also for the Pir Panjal—namely, the glaciers terminated in the shore region of the lake, and their outwash gravels and morainic débris were dumped into the Karewa Lake on top of the folded Lower Karewa lake beds.

One of the characteristics of this stage consists of the notable width and depth of the trough-shaped valleys. This is easily understood if we consider the weakness of the first glaciation and the intense erosional activity which preceded this stage. In view of the fact that there is no evidence for an earlier valley glaciation, it is not surprising that the morphologic effects of the second ice advance are so conspicuous and widespread. Trough-shaped valleys are imperfectly preserved because of the erosion, which even at present is extremely active. Physical weathering at high altitudes is powerful in itself, but when it is intensified by heavy

seasonal rainfalls and intermediate dry periods, the effects of frost splitting, nivation, insolation, and slope creep upon the upper valley slopes are much greater than in normal temperate climates. The result is that trough valleys were preserved more perfectly in regions where the glaciers had scoured the upper valleys deeply, so that glacial features more readily escaped subsequent denudation. This is exemplified by the perfect display of glacial action on the elevated plateau remnant of Tosh Maidan.

Tosh Maidan and Sokhnagh Valley

From the watershed range of the Pir Panjal, southeast of the Ferozepur Valley, there descend a number of flat trough-shaped valleys, all of which converge upon the pasture grounds of Tosh Maidan (figs. 80, 83; pl. XVII, 1, 3). Their ancient floors, which were dissected by subsequent glaciers, lie some 300 feet below the level of the high spurs and plateau remnants, which carry a veneer of ground moraine belonging to the first glaciation. (See pl. XIII, where a level divide can be seen to emerge from the range.) The central location of this region on the crest of the range and poor slope drainage account for the perfect preservation of those mature land forms which existed when the second ice advance began. These mature valleys were made wider by powerful ice tongues, which left thick ground moraines all over Tosh Maidan (M2, fig. 80, and pl. XVII, 1). In spite of the graded condition of the valley floors, glaciers must have acquired strong initial flow movement from their feeding grounds, because these were located at the foot of the watershed, which is dotted with huge cirques, some of them 1 mile in diameter (figs. 80, 83). As these cirques have precipitous walls, as much as 1,000 feet high, and as they are located on the lee side of the monsoon advance, snow and firn must have accumulated in them rapidly. When they had become filled to capacity, the ice flowed out with sufficient momentum to overcome the retarding influence of the low valley gradient. Hence it is natural that the valley slopes show the effect of ice abrasions, even in such areas of mature relief as Tosh Maidan. Peculiar to many of these flat trough valleys is the even transition into the plateau level, which we take to indicate that Tosh Maidan underwent little dissection prior to the second glacial period, in contrast to the upper valley portions of the Pir Panjal. This flatness of the relief caused the glaciers to overflow their channels and to coalesce, whereby a local piedmont glaciation resulted. At such places the ground-moraine filling also transgresses the flat valley trough and mantles the lower portions of low interstream divides. This explains why on the sketch map (fig. 80) the second ground moraine is not restricted to valleys.

In connection with this overflow phenomenon, it is to be noted that some trough valleys transgress the watershed. Examples of such high troughs piercing the Pir Panjal divide were seen at Basam Gali and in the valley half a mile southwest from that place (pl. XVII, 1). These troughs have undergone little alteration from weathering or eroding agencies, and they appear on the sky line as reliable witnesses to the sway which the second glaciation held over the watershed region. Troughs of this type are found only where the divide is lowest and where the upper valley

portion is flat and wide. (See also Paterson's report on corresponding glacial features on the Poonch side.) As hanging troughs are found only in connection with this glacial stage, it is obvious that the accumulation of ice must have been greatest at that time. But ice formation on a plateau remnant, such as Tosh Maidan, must have been of a special type.

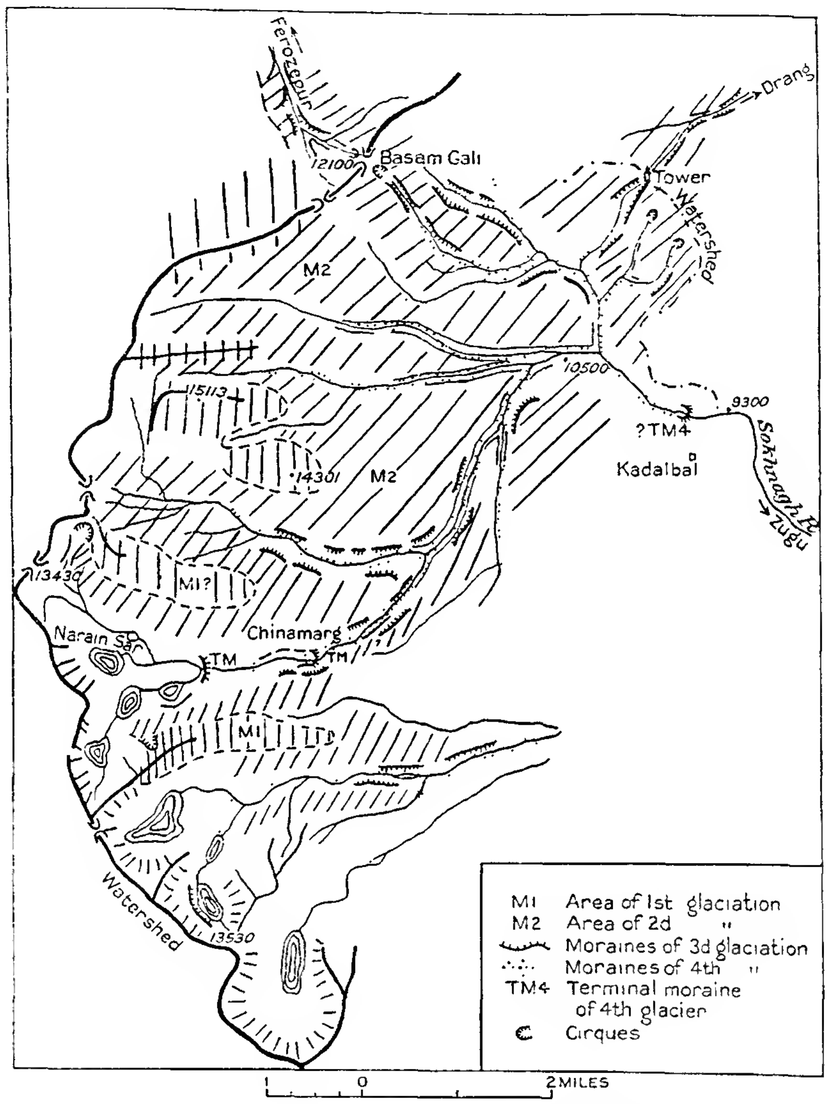


FIGURE 80.—Map of glacial deposits on Tosh Maidan.

It has already been mentioned that this region represents a collecting basin for many headwater streams. Fan-like, these rivers spread toward the divide, and in nine out of twelve valleys ground moraines are encountered on the floors of the first troughs (fig. 80). One can imagine now what this plateau basin must have looked like during a stage of intense glaciation. Not only were all these valleys filled with ice, but the ice overflowed, which caused individual ice tongues to merge

into one another. This in turn must have led to rapid ice filling of the basin, which now has a low divide (200 feet high) toward the Kashmir Valley. As the ice piled up in this "bowl," it finally flowed across the divide, catapulting rapidly down the steep slope toward the lake basin. This mechanism is clearly recorded (1) in the nature of the glacial deposits on each side of the divide and (2) in the relief of both divide and slope region.

As regards glacial deposits, the clay moraines of Tosh Maidan (so far as they can be assigned to the second glaciation) are altogether absent from the Kashmir slope. Instead we find here coarse boulder moraine mantling the slopes and extending beyond the valley outlets near Drang and Khag, where isolated erratic blocks indicate the farthest ice advance. There are no indications that this slope glacier had ever deposited anything else but boulder moraine, which is natural, considering the precipitous nature of the slope. From a phase of piedmont glaciation on the Tosh Maidan plateau the ice had passed into a stage of slope glaciation, characterized by hanging glaciers. Correspondingly the flat pass valley on which the ice had overflowed the low divide is replaced on the slope by a deeply incised gorge through which the Drang River, for a distance of 1½ miles, cascades 3,000 feet down to the valley outlet (fig. 80). Except for some broad and widely concave slope remnants in the upper valley portion there is no sign of the valley trough by which the glacier descended. It is probable that the ice overflowed from Tosh Maidan at many places and that most of the then existing slope valleys contained glaciers. This would explain the magnitude of débris accumulation at the valley outlets and the advanced position of huge erratic blocks, 2 miles beyond the mountain front, northwest of Khag.

Morainic outwash and boulder gravel form part of the great fans that characterize the foothills below Tosh Maidan. Their age is difficult to determine, as there seem to be two different deposits of boulder gravel—an older one with very coarse angular débris and erratic blocks and a younger one with clearly preserved terminal moraines. The younger gravel is superimposed on the older and covers part of the area. At first glance it is difficult to distinguish one from the other. Apart from the coarse angular nature of the older formation there is, however, one sure way of dating it—its relation to the Karewa Lake deposits. Near Drang and Khag it can clearly be seen that the morainic outwash, beyond the terminal moraine of the third ice advance, makes a valley fill in Upper Karewa beds (pl. XVIII, 2). The moraine itself is guided by the valley which is incised into the boulder fan and must therefore be younger. In other words, the moraines of the third advance are later than the Upper Karewa beds. These, on the other hand, are entirely free from glacial deposits, which appear only at their base in the form of the Karewa boulder gravel. This formation cannot well be seen except in the valley outlets, and, as the slope drainage of Tosh Maidan is not sufficiently effective to cut deeply into the fans, no exposures of strata older than Upper Karewa exist. However, between Khag and Drang there are many large erratic blocks lying about in the fields. These blocks have weathered out from Upper Karewa loessic silt and appear to lie on older lake deposits. In view of the loessic origin

FIGURE 81.—Outlet of Sokhnagh Valley near Zugu. G_2, second glacial; T_1, second interglacial; T_2, third glacial; LM_3, lateral moraine of third glacier; T_3, third interglacial; T_4, fourth glacial.

of their medium, it is quite possible that they originally rested on an older gravel which was eroded before the Upper Karewa silt was laid down and that they weathered out gradually as they were stripped of their cover. That these isolated erratics are but advanced outposts of the older boulder fan is indicated by the presence of large angular blocks in the fan.

The thickness of these boulder fans amounts to more than 400 feet, and, significantly enough, the maximum thickness was encountered at the outlet of the Drang Valley, through which the ice had flowed off the Tosh Maidan plateau. The maps show that these boulder fans extend for several miles along the foot of the range, and it is therefore obvious that the ice also occupied the smaller slope valleys, each of which contributed to the formation of fans.

The length of these Tosh Maidan glaciers can be approximately reconstructed from the extent of the clay and boulder moraines. (See pl. LV.) These moraines were presumably formed in the neighborhood of the present valley outlets, which must have bordered on the Karewa Lake. Ice tongues could not have extended much beyond this zone on account of the steep gradient and the shallowness of the lake. Hence the distance between these valley outlets and the upper firn region marks the approximate length of the glaciers, which was 7 to 8 miles. A much more powerful ice stream, however, must have flowed off through the headwaters of the Sokhnagh Valley, which has its outlet at Zugu Kharyan. This valley was studied only in its upper portion, where the trough succession is especially evident at Chinamarg (pl. XVII, 2). The wide trough remnant can be followed downstream to the vicinity of Kadalbal (fig. 80), where the river leaves the Tosh Maidan to flow in a gorge, 1,000 feet deep, to the valley basin. The great thickness of the boulder gravels (300 feet in the lower valley tract) is sufficient indication of the existence of a powerful glacier, which built this outwash fan into the estuary of the Karewa Lake. The total length of this ice tongue must have been 15 miles.

The relationship of the glaciofluvial outwash gravel, derived from this Sokhnagh Glacier, to the Karewa beds is clearly exposed in the valley outlet at Zugu Kharyan (pl. XVIII, 3). The funnel-shaped outlet is here filled with an alternating series of lake beds and gravels, the total thickness of which amounts to some 320 feet. This series is composed from the bottom up of Lower Karewa clays, boulder gravels, and Upper Karewa beds. Boulder gravel is prominently seen on the higher slopes (fig. 81), where it underlies terrace 1. These outcrops lie 270 feet above the present stream bed and can be followed away out into the basin, downstream for a distance of 5 miles. Here the gravel gradually diminishes in thickness from 50 to 10 feet, with the boulders getting smaller and more rounded toward the basin.

On the right bank, near the bridge at Raiyar Yech, it can be seen that the boulders are embedded in brown clay, which is slowly replaced downstream by a pure gravel whose fluviatile origin cannot be doubted. Evidently the clay matrix in which the subangular boulders rest must in some way have been connected with the accumulation of the coarse débris. This débris consists of granite, slate, amphibolite, and trap, all of which compose the region drained by the Sokhnagh

River. Some of the boulders are 20 feet in diameter and display striated facets. Generally, however, they are water-worn. The percentage of faceted boulders increases gradually upstream, and so does the thickness of the clay matrix. In fact, it seems that this deposit gains rapidly as the trough remnant of the second glacier is approached. A mile upstream from the bridge this formation composes the higher forested slopes, and its thickness here exceeds 200 feet. It is evident that such a peculiar sediment, in which both faceted and water-worn boulders appear in a clay matrix, can have originated only at a time of strong valley glaciation. The Sokhnagh Glacier presumably terminated here in an estuary of the lake and dumped morainic débris and clay into it. In such a process clay must have been washed out first, and it presumably was kept in suspension for some time while the river continued to transport débris off the ice front. After some time clay precipitated upon the boulder gravel, and this may have occurred repeatedly, until the glacier finally retreated so far upstream that its waters were unable to transport débris down to the lake. At this stage boulder gravel accumulated in the middle valley tract, and it is this formation which is always encountered in a high gravel terrace below which lie the moraines of the third glaciation. The boulder gravel, therefore, is a kind of lacustrine glacial outwash deposited during a phase of maximum glaciation. It is analogous and homotaxial with the second glacial outwash of the Sind Valley described by Paterson. That this phase followed upon the formation of the Lower Karewa beds is clearly proved by the superposition of boulder gravel upon folded Karewa lake clays. The lowest outcrop along the river, at the bridge, exposes this unconformable contact of the two formations (pl. XVIII, 4). The extraordinary increase in thickness of these lacustrine gravels at the valley outlet supports our contention as to the accumulating effect of a stagnating glacier upon the sedimentation of a lake estuary.

Second Interglacial Stage

The next stage of deglaciation is recorded in (1) deposition of Upper Karewa beds, (2) erosion, and (3) the formation of terrace 1.

1. Upper Karewa yellow silt and loam lie on the boulder gravel, the fan structure of which is veiled by a 40-foot layer of soft sediments (fig. 81, below T1). This makes for inclined, even surfaces which are so characteristic for all valley outlets of this foothill region. Pine forests carpet these even relief forms, the former interrupted only by maize fields or forest meadows. How much of this 40 feet of silt actually belongs to the Upper Karewa beds or to a younger soil is difficult to tell. Individual profiles usually show a stratified and shell-bearing brown or yellow loamy silt, overlain by 4 to 7 feet of dark stained soil. The soil presumably belongs to what we have previously called postglacial loess, because it begins here, as everywhere else, with a 2- to 3-foot band of carbonaceous clay, charged with pollen. The underlying silt is slightly lighter in color than the clay matrix of the boulder gravel, but in places they are difficult to distinguish from one another. This silt apparently represents the late loessic phase of Upper Karewa time. It may well have been laid down during the retreat phase of the ice. Being of lacus-

trine origin, this silt increases toward the valley basin, in contrast to the underlying boulder gravel, which diminishes in thickness. This behavior illuminates the difference in origin between the glacial and interglacial lake deposits.

2. The Upper Karewa clay mantle is greatly dissected, as can be seen from the map. On the left bank of the Sokhnagh River its surface is at 7,600 feet, and a steep slope leads from it about 60 feet downward to T1. This is really a ledge developed on resistant boulder gravel from which the Upper Karewa beds were stripped off. At first sight it seems as if differential slope erosion rather than river action had formed this ledge. On the other hand, there is good reason to believe that at one time this ledge was part of an old valley floor, shortly before the next great slope was formed, and it is this slope which represents the erosion period of second interglacial time. This contention is supported by the fact that an upper terrace (T1) is uniformly present even in regions where the Upper Karewa beds are missing, as along the Sind and Jhelum rivers.

3. If terrace 1 represents an old valley floor, it is evident that the Karewa Lake must have previously been drained off. This event presumably took place at the beginning of this second interglacial period, when the valley glaciers had retreated to the upper valley tracts. The thinness of the Upper Karewa beds in this region suggests that the lake had shrunk considerably ever since the narrowing of the basin (through previous folding) had taken place. Hence, the snow waters of the retreat stage during the second glaciation in this region may have flowed into dry lake beds, and it is to their action that we assign this relief making of post-Karewa time.

Below this terrace 1 there is a prominent slope, 90 feet high (fig. 81 and pl. XVIII, 4, below T1), against which rest lateral moraines and corresponding glaciofluvial gravel of the third glaciation. From the depth of the entrenched valley we may conclude that this represents the first great erosion of post-Karewa time. This, however, does not mean that the time required for the first dissection was necessarily very long, for obviously the Karewa clays make for easy denudation. This can at present be observed in all gullies where Upper or Lower Karewa beds are subject to erosion. One generally tends to overestimate the time required for relief making in unconsolidated formations. From my own observations I know that gullies 60 feet deep have been cut within a period of 10 years into postglacial valley fills at the foot of the Rocky Mountains in Colorado. As the ancient valley floor presented a wide flood plain at the time of the third ice advance, the stream must then have already entered a stage of lateral erosion or beginning maturity. This fact and the absence of an interglacial gravel fill speak for structural rather than climatic control of this erosion. For we must recall that this long interglacial stage was a period of decreased rainfall during which river action could not have been brought about by the general uplift which the Himalayan and Pir Panjal regions witnessed in this period. Evidence for this movement has already been presented and will be discussed once more in the following pages.

Upstream from the valley outlet this prominent slope continues for many miles. The wide glacial trough of the second Sokhnagh Glacier, so far as it can

still be recognized, is deeply incised, and in this new valley are encountered the lateral moraines of the third glacier (pl. XVII, 2). These relations were clearly observed in the Tosh Maidan region. The picture of the morainic amphitheater (fig. 80) shows that the ground-moraine filling was dissected before the third glacial advance took place. The height of the slope against which the third moraines rest ranges from 90 to 200 feet, but it must in reality be much greater, because the thick moraine filling conceals the true depth of the interglacial valleys. Obviously these valleys were completely free from ice for a long period of time, and as they continue away back to the watershed range, it is clear also that the second glaciers had at that time retreated to the cirque or firn region. In other words, the second interglacial period was a time of complete deglaciation—a conclusion which is in full accord with our contention that this stage was one of long duration.

Third Glaciation

Although the records of the third glacial stage are in some respects fuller than those of the second ice advance, it should be noted that the glaciation was less strong. Its characteristics in this region are smaller and thinner moraines, well-developed trough valleys, and terminal moraines lying in well-advanced position in or beyond valley outlets (fig. 81, pl. XVIII, 2, 3).

Beginning with Tosh Maidan and the elevated tract along the watershed, two features are of special importance. One is the clear differentiation of smaller individual glaciated valleys with lateral moraines, and the other is the restriction which this glaciation experienced in relation to the watershed boundary of the Pir Panjal. Figure 80 shows that these glaciers originated in cirques which lie near the pass region formed by dissected trough remnants of previous glaciers. At Basam Gali, for instance, a cirque is found some 400 feet below the divide, and from this point a lateral moraine can be followed downward to the main plateau level (pl. XVIII, 1). This feature is repeated many times all along the watershed wherever troughs of the second glaciers were preserved. This we take to indicate that the divide was dissected (by uplift) prior to the third advance and that subsequent glaciation was not sufficiently strong to overcome this obstacle and to develop glaciers transgressing the divide. This glacial overflow, as has previously been pointed out, was typical of the second glaciation around Tosh Maidan, which at that stage acted like a bowl in which ice accumulated to the brim. Overflow occurred here only toward the Kashmir Basin, but then the exit was gained by means of preexisting valleys.

Such glacial advance on the slope took place in the Drang and Sokhnagh valleys. In the Drang Valley lateral moraines are visible above the forest rest house near Drang. From this place they can be followed downstream along the incised valley north of the village to a point 200 yards beyond the place where the road from Hatbar crosses the stream bed (pl. XVIII, 2). Here lies a terminal moraine (at 6,850 feet) some 30 feet high, with a dissected glaciofluvial fan spread in front of it. A few furlongs farther on there is another accumulation of large angular boulders, some of which show unmistakable facets and striation. This

moraine is less distinctly preserved, but it presumably marks another stagnation of the same valley glacier. As has already been pointed out, these moraines are younger than the Upper Karewa beds and younger also than the valley-making period which succeeded the emptying of the lake basin. This explains why the moraines follow the drainage lines faithfully, just as on Tosh Maidan. Another one is found 1 mile north at Shungilpur at 6,700 feet (not indicated on pl. LV). Its relation to the boulder fan is again signified by the incised position of the morainic valley. Above Khag large heaps of boulder moraine are encountered in the forested region at 6,800 feet. These look like kames or eskers, but as they are greatly weathered and have been destroyed by repeated river floods, it is hardly possible to recognize their origin. These elongated low boulder ridges lie at the very outlet of the Mangi Nar Valley—a position which might suggest that they belong to a terminal moraine dissected by younger streams. Such dissection is still going on, for the Mangi Nar River branches out into seven major channels, all of which flow across the boulder fan. This explains why the terminal moraine walls have been much better preserved three-quarters of a mile downstream, in the immediate vicinity of Khag. Here at 6,500 feet is an elongated ridge of boulders which is cut into by two stream channels. Traces of another moraine wall lie a quarter of a mile northeast of the village. This ridge has coarse outwash gravel emerging in the form of a gravel terrace which makes a thick gravel fill in the valley. Altogether, then, there are two, if not three, moraine ridges, and as in two of them the lobate shape of terminal-moraine walls can approximately be reconstructed, we take these to represent two stages of glacial stagnation. The higher one obviously is a retreat stage of the same glacier. This feature is typical for the third glaciation and is described above from the Himalayan slope in the Sind Valley near Gund.

More prominent still are the moraines in the outlet of the Sokhnagh Valley (fig. 81 and pl. XVIII, 3). Almost 1 mile north of the bridge the road crosses a long curved boulder hillock which is composed of large and small angular blocks. A similar wall, transversely situated to the valley, is found half a mile upstream. This suggests again at least two moraine walls, both of which lie at 7,200 feet. Their position in the valley below the Karewa surface proves that the third Sokhnagh Glacier advanced into a relief previously cut into lake beds. In comparison with the Tosh Maidan the moraines of the third Sokhnagh Glacier are much thicker and more widely distributed. No doubt this is due to the wide funnel shape of the valley outlet which promoted the formation of a glacier lobe, as the shape of the two moraine walls suggests. That these were preserved only on the left bank is not surprising, as the river still swings to the right, a tendency which it must have developed in the third interglacial stage, when terrace 3 was cut as a wide plain into the moraines. On the left bank, below Rangazabal, a lateral-moraine wall is found. It stands out as a conspicuous ridge, some 50 feet high, and was followed upstream as far as the first sharp bend of the river. Here also appears the corresponding moraine on the right bank. The distance from the inner slopes of these lateral moraines across the valley is about 1,200 feet, and this figure may

indicate the width of the third Sokhnagh Glacier before it spread out in lobate fashion. The lobe itself may have been three-quarters of a mile wide and was presumably thin, as the moraine walls rarely stand 80 feet above terrace 2, which was cut into outwash gravels of this glaciation. These outwash gravels are extremely coarse and might at first be taken for morainic débris, especially as their matrix is fine-grained. No clear contact between gravel and moraine was seen, but the moraine rises in knoblike masses and broken ridges above the terrace ledge, whereby the glacial topography is set in contrast to the fluvial terrace.

Terrace 2 (fig. 82) is of aggradational origin and developed directly out of redeposition of morainic débris of the third glacier. This is indicated by (1) the gradual merging with lateral moraines, (2) the content of subangular faceted boulders derived from the third moraines, and (3) the absence of a distinctive erosional slope against the moraines. The gravel is of great thickness, as the erosional slope below terrace 2 is 40 feet high, exposing throughout a very coarse sediment. This terrace gravel can easily be distinguished from the older Karewa

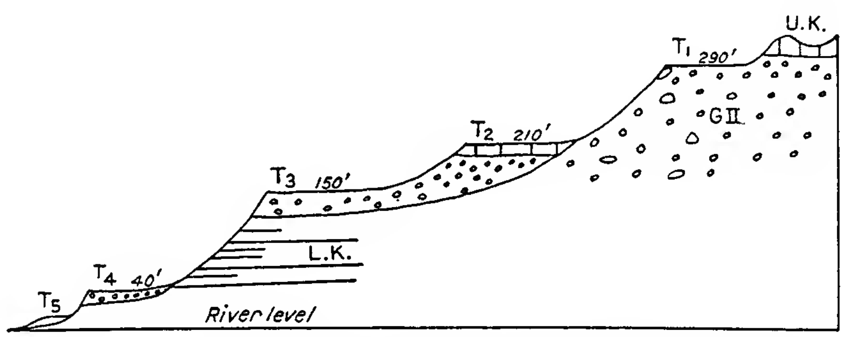


FIGURE 82.—Cross section through right slope of Sokhnagh Valley opposite Zugu. T1, T2, etc., terraces; L.K., Lower Karewa beds; GII, second glacial gravels; U.K., Upper Karewa beds.

gravel by its gray coloring and lack of clay matrix. From the younger gravel of terrace 4 it is differentiated by its greater thickness and content of large subangular boulders. It is a glaciofluvial deposit succeeding the maximum advance of the third glacier and filling the ever-widening river channel as the ice retreated upstream. This explains the wealth of coarse boulders derived from both lateral and ground moraines, and it accounts also for the greater thickness as compared with the thinner gravels of the fourth glaciers, which were much shorter. This second terrace can be followed from a point above the bridge down to Waragam, a distance of 4 miles, and on its way it follows the river faithfully, gradually becoming less coarse and thinner. No boulders were observed half a mile beyond the hypothetical glacier snout at Zugu Kharyan. Very striking is the fact that the level of terrace 2 is inclined as against the present stream bed. This feature is discussed in the chapter on terrace tilting, and therefore no further mention of it will be given here.

Of great interest is the appearance of a gravel terrace in the valleys of Tosh Maidan. It is incised into ground moraines (GM2, fig. 83) and in places shows a gravel fill which itself is entrenched by channels containing moraines of the fourth

glaciers. Large erratic blocks weather out from the terrace and may have been dropped by the glacier on its retreat to the watershed. Obviously, then, this gravel is somewhat younger than the terrace gravel in the valley outlet, and one might feel inclined to consider it as an interglacial rather than a glacial deposit. However, we reason that the glacier had not yet fully retreated to the cirque region because of the lasting deposition of glaciofluvial sediment prior to the erosion by which the following interglacial stage was recorded. Glaciers must still have existed at that time, and complete deglaciation, marking the beginning of the third interglacial stage, may have followed shortly after.

Third Interglacial Stage

That the valley glaciers had completely retreated is indicated by the dissection of the third valley troughs on Tosh Maidan, which allowed the fourth glaciers to advance in narrow, steeply entrenched channels (fig. 83). Here the third deglaciation was recorded by erosion and the formation of a degradational terrace (3). No deposits of third interglacial age were observed on the slope. It is possible that

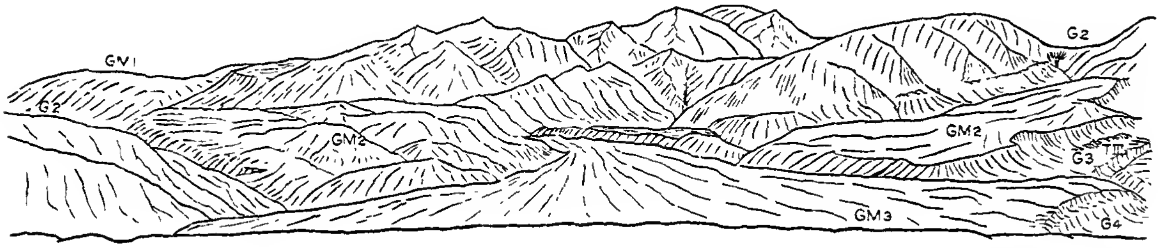


FIGURE 83.—Sketch of Tosh Maidan panorama. GM1, GM2, etc., ground moraines; G2, G3, G4, glacial troughs; TIII, terrace.

they existed and were removed by erosion, but if so one would expect to find some sort of depositional record in the basin. Such records are missing, and hence we believe that during this stage the range was again passing through a phase of unchecked erosion. This term should remind one of the possibility that the incentive for erosion—namely, uplift—had always been there, but that stream action was checked by glaciations which were the intervals in a more or less continuous process of erosion and rejuvenation.

Terrace 3.—On Tosh Maidan terrace 3 can be identified only at places where it is found cut into the ground-moraine filling of the third glacial troughs (fig. 83). Such a terrace remnant was observed 1 furlong upstream from P. 10,210 feet about 1 mile southwest of the watch tower on the Drang road (pl. XVIII, 2). Unquestionably, this is the wider of the two terraces present, and, seen from a vantage point, it stands out conspicuously as a flat bench incised by streamlets. These have been entrenched by valleys 40 feet deep, and in them we encounter younger morainic débris and occasionally also terminal moraines belonging to the last glaciation and to late glacial retreat stages. The terrace is cut back into the ground moraines of the second glaciers, as also into the lateral moraines of the third glaciers,

but no opportunity presented itself to study the relationship between it and the higher gravel terrace (T2). It is, however, evident that the lower terrace succeeded the third glacial advance and that it originated at a time when rivulets flowed down valleys choked with morainic deposits. These interglacial streams apparently did not dissect the moraine filling, but they eroded laterally, until a new incentive for rejuvenation was given. It is possible that this lateral erosion resulted from a temporary crustal stability, as observations on the lower valley portion indicate.

Again the gorgelike character of the middle course forbids the reconnaissance of terrace remnants, but above Ingu a wide terrace can be seen along both sides of the river. It is the third terrace from the top and, as on Tosh Maidan, the widest. The slope is either cut into the lateral moraines of the third Sokhnagh Glacier or into the corresponding glaciofluvial gravel. Its level lies 140 feet above the stream bed and is somewhat uneven, owing to a loam cover in which rain wash and smaller tributaries have cut a slight relief (fig. 81). The terrace loam is of brown and yellowish color and consists of fine silt with superficial pebble accumulation. The pebbles may easily be derived from gravel washed down from higher slopes and therefore do not necessarily indicate a river drift contemporaneous with the loam. This deposit somewhat resembles the loessic silt found in similar or younger terraces of the Jhelum River. It may be a fluvial deposit that was spread over the terrace when the stream meandered across the wide valley floor.

Farther downstream, terrace 3 can be followed for many miles into the valley basin as far as Zugu Kharyan, where it is cut into a low ridge made of slightly cemented gravel. As the gravel is overlain by 10 feet of Upper Karewa clay we must assign it to the Karewa gravel, which permits us to date the terrace here as post-Karewa. From the absence of the second terrace gravel we conclude that the terrace in question is T3.

The regional occurrence and uniform characteristics of T3, both in the Tosh Maidan region and in the lower valley, indicate that the river was graded in these areas. What happened in the intermediate region, where the stream broke through the range, is difficult to tell owing to lack of observations. We presume that it had reached a gradient sufficiently small to prevent vertical erosion in the lower tracts. In other words, the formation of this terrace required relatively stable conditions, such as might have resulted both from crustal quiescence and from the weakness of interglacial stream action. These considerations argue in favor of the contention, mentioned above, that it was the stability of gradient rather than the nature of the valley fill which led to lateral erosion and terrace formation.

This phase apparently was followed by vigorous rejuvenation of the relief to which the prominent slope below T3 testifies (figs. 81, 82). At Zugu Kharyan this slope is 105 feet high, and on Tosh Maidan it is 30 to 40 feet. The headwaters evidently resumed the entrenchment of former periods before the last ice advance occurred.

Fourth Glaciation

In comparison with the preceding two ice advances the last Pleistocene glaciation was the least significant, but its records are clearly visible in some major

valleys. Where these had been glaciated both terminal and lateral moraines are present, and in the nonglaciated lower valley tracts a terrace is found (T4) which to all appearances belongs to this stage. The main characteristics of this last glaciation were (1) narrow and short valley glaciers which did not reach below the levels now at 9,000 feet, and (2) restriction of such glacier formation to the headwaters of the Sokhnagh River and its upper valley portion.

In addition, we observe that there are no sure traces of this glaciation either in the Drang Valley or in the foothills near Drang and Khag. This negative evidence is corroborated by the fact that small cirques were found on the Tosh Maidan side of the pass valleys, and from these cirques small ice tongues originated, which followed the present headwater drainage to the main overflow in the southeast corner of the plateau (pls. XVI, XVII, 4; fig. 80). In other words, a reversal of ice flow had taken place; glaciation was in many localities not sufficiently strong to overflow or break through the pass valleys leading to the Kashmir Basin. This situation (fig. 84) is easily understood if one takes into account the weakness of the glaciation and the dissection of the Tosh Maidan relief in the preceding stage, following the terrace formation. At this time a watershed between the plateau remnant and the Kashmir slope had formed which not even the Drang River could transgress. Drainage that had previously flowed off this side was diverted toward the Sokhnagh River, and when the new firn accumulated, it formed cirques on the inside of the glacial "bowl" at the head of the newly formed valleys. This reversal of ice flow repeated on a smaller scale what had previously happened with the third glaciers along the watershed range and, as in that case, it was brought about both by previous relief making and by a smaller supply of ice. This phenomenon is in itself an indication of the lesser degree of glaciation, but in addition there are other proofs.

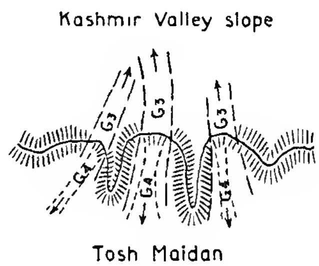


FIGURE 84.—Reversal of ice flow on Kashmir side of Tosh Maidan. G3, third glacier; G4, fourth glacier.

In the upper portions of the headwater streams one encounters low ridges, made of block moraine, through which the rivulets break. They lie 30 or 40 feet below the level of the lower terrace (T3). According to their shape we can differentiate humps of morainic débris which are transversely located and others which tend to follow the river course. The former are evidently terminal moraines deposited during a late retreat phase of the last glaciers. In view of their high altitude (12,500 feet) and their position in front of the wide cirque basin of Narain Sar (fig. 80), and considering also that lateral moraines continue much farther downstream, we assign them to a post-Pleistocene or subrecent ice advance. The fact that lateral moraines may be encountered for many miles along the slopes of the major headwater valley down to a level of about 9,500 feet makes us suspect the existence of a lower terminal moraine. This apparently is found half a mile north of Kadalbal, on the edge of Tosh Maidan, where the river begins its fall through the Zugu Kharyan forest (fig. 80). Here the narrow outlet is choked

with boulders, as if a small glacier had halted, dropping its load into the steep valley below. No information is available as to the existence of other moraines from this glacier farther downstream, and hence we cannot be too certain of the position of the fourth terminal moraine near Kadalbal. This outlet of Tosh Maidan, however, must have at one time caused a halt in the movement of the fourth glacier, because even now it marks a sharp nick in the valley gradient. The altitude of this place is 9,300 feet, or 2,400 feet above the third terminal moraine near Zugu Kharyan. If this position is accepted one may well say that the fourth Sokhnagh Glacier was very much shorter than the third, a conclusion which is wholly in accord with what has previously been stated in regard to the weakness of the fourth glaciation.

Terrace formation.—The nature of the fourth terrace in the valley outlet at Zugu Kharyan supports this contention. Its composition reveals a greater uniformity of pebbles derived from crystalline and igneous rocks of the headwater region. In addition, there are no angular boulders, such as occur in T3, and the pebbles are water-worn and well sorted. Although direct derivation from the fourth moraines cannot be proved, it is nevertheless highly probable that this terrace gravel signifies a period of intense outwash, following the dissection of T3. The gravel is banked up against the slope, and the terrace level lies 40 feet above the stream bed. This filling of the third interglacial valley floor with fourth glaciofluvial outwash is, as will be shown later, a phenomenon common to all the valleys. Like the previous terraces, this level can be followed downstream to Waragam and farther toward Buna. Here, as on T3, a thin cover of silty loam is encountered, whose origin is discussed farther on.

Below this terrace are preserved remnants of a flood plain, which lies 10 feet above the stream bed. In view of the incomplete preservation of this youngest boulder gravel, it is better to discuss its nature in the following section, in connection with the study of the terraces along the Vishav River.

Valley Tracts of the Vishav and Rimbiara Rivers

About 15 miles from the outlet of the Sokhnagh Valley, the Rimbiara and Vishav rivers enter the Kashmir Valley. These streams drain the highest region of the Pir Panjal, in which glaciation is still relatively strong. The western tributary of the Vishav, called Harseni Nar, has its source at the snout of a small valley glacier below the Budil Pass, and some of its tributaries are derived from similar sources. The major branch of the Vishav, called Zaji Nar, was not visited, and in the Rimbiara Valley observations did not extend much above the village of Hurapur. Hence the following discussion of glacial records is based on observations made in the lower valley portions and also along the entire length of the Harseni Valley.

In view of the completeness of Pleistocene records in this area, it seems advisable to defer the description of the region intermediate between the Tosh Maidan and Rimbiara rivers to the end of this section. This procedure will allow better interpretation of that intermediate tract in which observations are far less

complete. The clearest understanding of the glacial history of this region can be gained from a description of the Vishav Valley and its major tributary, the Harseni Nar.

Harseni and Vishav Valleys

The common approach to the beautiful alpine Harseni Valley is by way of the Tsurugul Pass (9,407 feet), which is situated on the divide between the Rimbiara and Vishav drainage systems (fig. 85). From this pass the view opens toward magnificent scenery (pl. XIX, 1). The undulating yet steeply sloping relief in the foreground, on which patches of pine forest grow, is made of boulder moraine (GM2) from which large erratic blocks have weathered out. Above the incision of the stream there becomes visible a terrace remnant (T, pl. XIX, 1) which is found in a trough (G3) whose light-gray fan-covered slopes contrast with the darker bedrock of the higher valley flanks. Spurs leading toward these flanks are faceted (G2), and the rock is here striated. Above these remnants of a glaciated valley there is a visible flattening of the relief, and a planed surface forms part of the watershed range, some 4,500 feet above the valley bottom. This elevated planed surface is part of the preglacial relief of the Pir Panjal and calls to mind the topography above Tosh Maidan. Here, as there, we may well expect to find a thin mantle of ground moraine on this highest level, but this was not investigated. In order to gain a chronologic picture of the relationships between these relief units it is best to begin with this preglacial surface.

Second Harseni Glacier.—The planed level is surmounted by the watershed range, in which lie several névé fields and glacierets (pl. XV, 3). Below it appear two remarkable features—namely, hanging valleys and a nick of the slope profile. The nick has previously been analyzed as a slope of the first interglacial valley. As to hanging valleys (pl. XIX, 1, HV), it may be seen that their level (13,000 feet) approximates that of the upper limit of the trough remnant (G2) found above the fan-covered slopes. Apparently both features are related to each other. The "trough shoulder" reaches up to the points where the wide hanging valleys enter the main valley. These valleys take their origin from wide cirques whose level is commonly found at 13,300 to 13,600 feet, as a study of topographic sheet 43 K/10 will prove. Inasmuch as this cirque level is so uniform, its origin may date back to a time when the headwaters of the tributaries were cutting back toward the range at an approximately even level. This doubtless was the same period which saw the dissection of the preglacial relief, for otherwise it would be difficult to explain the sharply dissected slopes between the top level and the hanging valley. It is to the drainage of the first interglacial period that we ascribe this headward erosion. Consequently cirques, hanging valleys, and highest trough remnant all belong to one and the same glaciation, which was the second from the top, or the first true valley glaciation of the Pir Panjal.

Although little was preserved of the major trough of the second Harseni Glacier but faceted spurs and striated bedrock, there is still sufficient indication left for the recognition of a very wide trough. Such a trough may be seen in a side valley opposite Shahkut (pl. XIX, 2, G2) where its U shape contrasts remarkably

with the planed level of the preglacial relief above (PG). The width of these valleys is in itself proof for the preceding dissection of the mature relief, and, on the other hand, it permits us to visualize the intensity of the second glaciation.

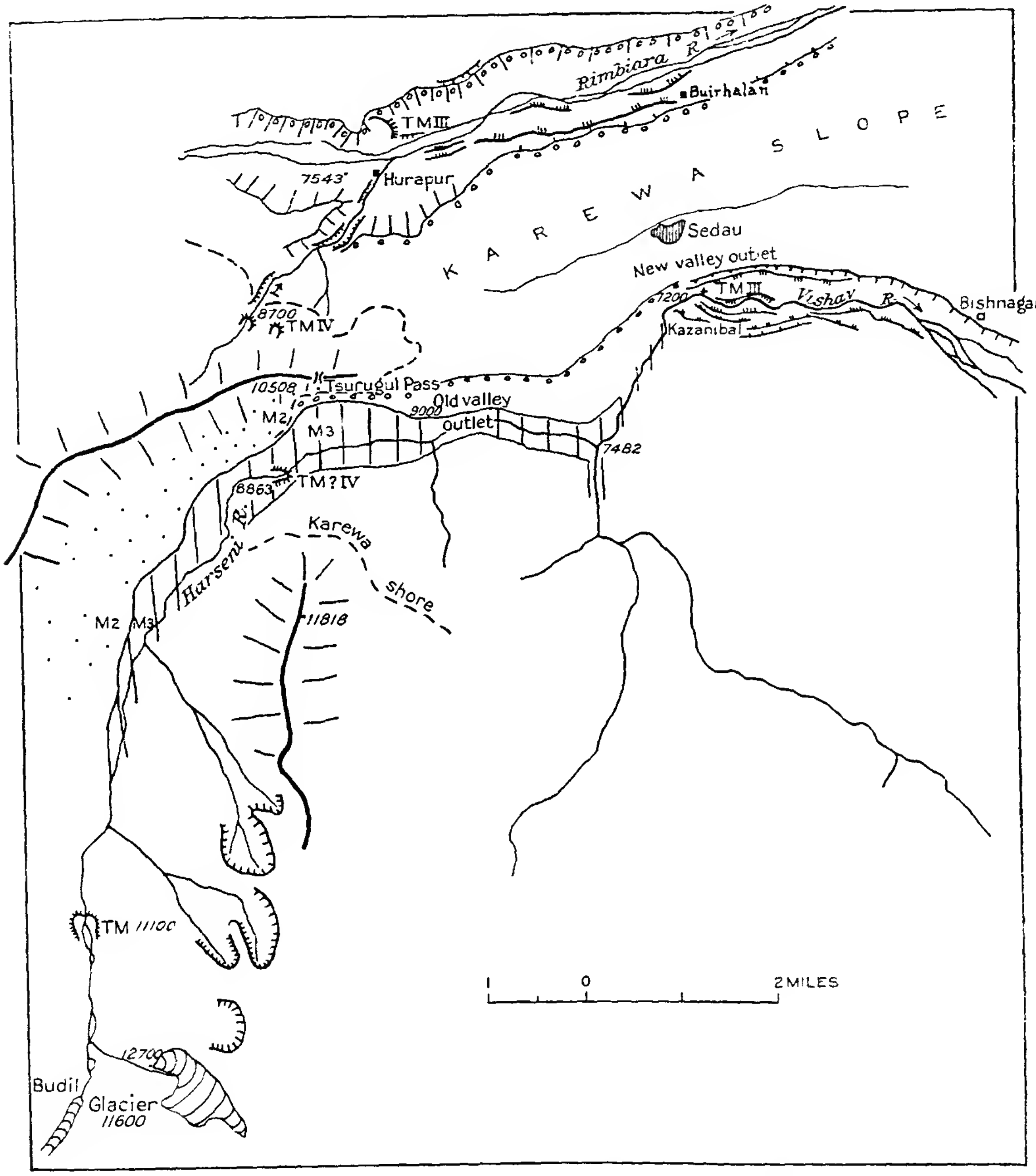


FIGURE 85.—General map of Harseni and upper Vishav valleys.

The farther downstream one proceeds, the more morainic débris is encountered. This débris rests against the striated flanks of the trough G2 and attains a thickness in excess of 400 feet. The clay content indicates a ground moraine, part of which was denuded in subsequent periods. It becomes progressively

charged with boulders, until 1 mile southeast of Tsurugul Pass the first signs of fluvial action appear. The boulders are mixed with rounded pebbles and gravel covered with yellow clay resembling the Upper Karewa clay. The clay lies at an altitude of 9,100 feet, or 600 feet above the valley floor. At the same time the relief becomes more even and undulating (pl. I, 3), characteristic of the Karewa slope as described from the Sokhnagh outlet near Zugu Kharyan. In fact, as one comes on the forest path to Sedau it seems as if the valley outlet had already been reached, but in reality it is still over 2 miles away. This impression is given by the termination of the higher valley trough at the slope of the mountain front and also by the continuation of the lower valley toward the Kashmir Basin (fig. 85). The deeper significance of this feature is revealed on page 150. At Shahkut too, along the left valley flank near Lazgasan, it is easy to follow the process of progressive water wear of the morainic débris. The boulder gravel under the Karewa cover is over 100 feet thick and is rolled all over the slope down to the next terrace. The distance from the true moraine to this point is 1½ miles, and here the ground moraine of the second glacier is transformed into a thick glaciofluvial fan which lies 500 feet above the valley bottom.

An exposure of varved clay lies directly on ground moraine due south of the pass below the path to Sedau. Only a few feet of varved clay can be seen below the Upper Karewa clay, but this is sufficient indication of the temporary ponding of waters in the old valley outlet during the second glaciation. Indeed, if the clay on top of the boulder gravel is really Upper Karewa, it follows that this region was once an estuary of the Karewa Lake into which the second glacier dumped its débris. Morphologically the relation between the second trough valley and Karewa beds is well expressed in plate XIX, 3, where the redeposited ground moraine (GM2) can be projected into the more distant second trough (G2).

Analogously to the situation at Zugu the boulder gravel forms a huge outwash apron in front of the second moraines. Instantly the question arises, what position does this gravel occupy in relation to the Karewa Lake beds?

The Karewa gravel, forming a glaciofluvial fan above Sedau, is well exposed on the left bank of the stream and can be followed for more than 4 miles, from the hill slope of Sedauthur toward Bishnagar. At Sedauthur it lies at 7,500 feet and is 85 feet thick; at Bishnagar its thickness has decreased by 20 feet. Simultaneously a decrease in coarseness was observed. At the outlet near Sedau boulders average 3 to 4 feet in diameter (some of them are 7 feet) and all are subangular, their striated facets being slightly rounded by stream action. As at Zugu, the gravel is ocher-colored and mixed with brown sand, and the boulders are stained and rather weathered in contrast to the fresher appearance of the younger terrace gravel. That this fluvioglacial outwash fan underlies the entire tract between the Rimbiara and Vishav rivers is proved by the appearance of boulder gravel in all valleys and deeper ravines in which the overlying loam and silt have been removed (fig. 86).

The relation of this outwash to the Lower Karewa beds is indicated in figures 86 and 87, in which the unconformity is clearly revealed. Downstream the Lower Karewas gradually dip below the stream bed, so that the gravels replace the older

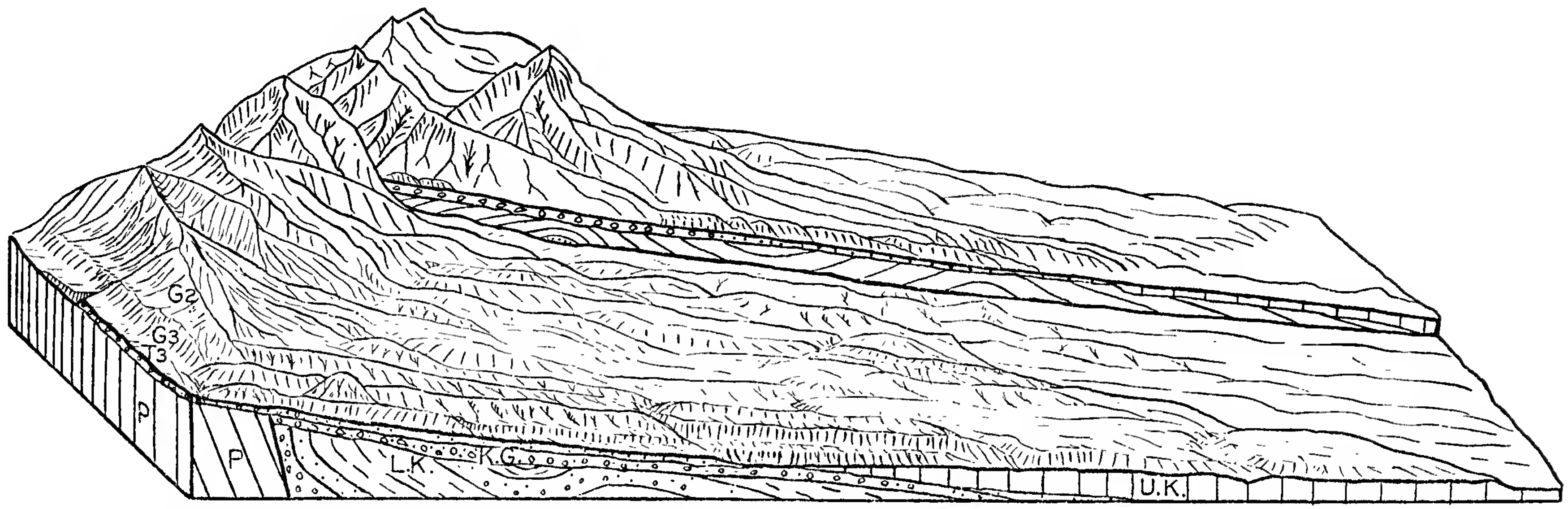


FIGURE 86.—Block diagrammatic sketch of region between Vishav and Rimbiara rivers. K.G., Karewa gravel; U.K., Upper Karewa beds; P, Paleozoic bedrock; L.K., Lower Karewa beds; T3, terrace; G2, G3, glacial troughs.

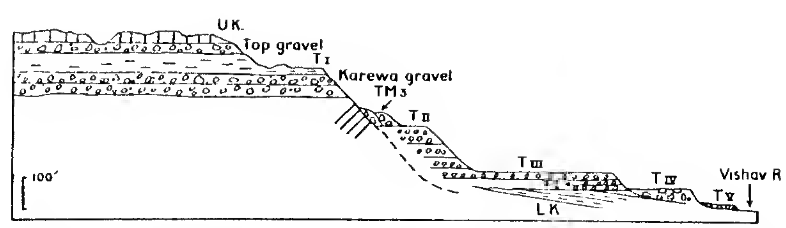


FIGURE 87.—Cross section through left slope of Vishav River below Sedauthur. U.K., Upper Karewas; TI, TII, etc., terraces; TM3, terminal moraine of third glacier; L.K., Lower Karewas.

lake beds. At the same time the Upper Karewa silt gains in thickness until it finally covers the records of earlier periods.

The survey of the left valley slope near Sedau revealed the presence of a higher boulder gravel, which is separated from the lower by a sheet of brown loamy silt (fig. 87). The upper gravel has a few feet of loam on top and lies 76 feet above the major outwash fan. Its thickness is 30 feet, from which we compute that the intermediate brown silt is 46 feet thick. This top gravel also is of glacial origin, as a few faceted boulders indicate, but its components are more water-worn than those of the underlying major gravel. The intermediate loamy silt must be assigned to a preceding stage during which no morainic outwash was accumulated. This can be explained only by lack of glaciation, owing to extensive shrinkage of the ice, when finer silt and clay were washed out of the ground moraines above Sedau. Considering this, the top gravel can only represent a new ice advance, but the rolled condition of its components suggests that the morainic outwash had longer stream transport and hence its terminus must have lain farther upstream than that of the preceding major glacier. In other words, the ice, after having retreated for some time, advanced once more and superimposed a second and less significant outwash fan above the intermediate loessic loam. The following discussion of the records left by the second interglacial stage shows that this last ice advance was a subphase of the major second glaciation.

Second interglacial stage.—The period of erosion that followed the second ice advance becomes manifest not only in the trenching of the lower slope region above Sedau, but in that of the higher valley tract as well. The wide trough which the glacier had left in the upper Harseni Valley was dissected (pl. XIX, 1). Fans were formed at the outlets of tributaries, and headward erosion gradually cut back into the hanging valleys; in this process waterfalls may have had a share. The sharp nick in the valley slope, below the trough of the second glaciation, is visible only where there is no cover of fan detritus. The fan merges with a younger moraine filling (G3), which we assign to the third glaciation. Tributaries were deeply cut into the valley walls, forming gorges that terminate at the upper limit of fans, as they should if the major valley had not yet reached its present depth. This makes for a distinct nick in the longitudinal profile of the tributaries, coinciding with the upper border of the third trough.

Farther downstream, interglacial erosion resulted in an effective removal of the older ground-moraine filling (GM2 in pl. XIX, 3). Here it is possible to estimate approximately the amount of vertical cutting from a comparison of levels between the valley floor of the third glacier and the upper limit of the ground moraine. This difference amounts to 650 feet. Below the Tsurugul Pass ground moraine is blanketed with brown loamy silt. This formation resembles in all respects the Upper Karewa silt, yet no good exposures were found in which stratification was clearly visible. For this reason it is impossible to say whether this deposit belongs to the early fresh-water stage of Upper Karewa time or to the later loessic stage. The glacial-lake deposit, mentioned above, unquestionably underlies this loam, and its formation might therefore have taken place during the temporary retreat of

the ice. The overlying loam might then be correlated with the deposit that covers the top gravel near Sedau.

Previously attention was drawn to the morphologic division of this region into a higher and a lower valley outlet (fig. 85). The higher outlet is made by the termination of the higher valley, chiefly of the second glacial trough, at the slope of the range; the lower one marks the terminus of a younger valley extension in which the third glacier advanced toward the basin into the Karewa relief. The two outlets are a little more than 2 miles apart, and between their respective levels is a difference of 1,000 feet. Whereas the glacial records of the second glacier terminate at the higher outlet, moraines of the third glacier extend 3 miles farther downstream in the younger valley extension. As the outwash apron of the second glacier begins at the higher level, it is not possible to explain such relations by denudation of the older moraines. They reflect rather a difference in level which existed at the time of the third glacial advance. Such differentiation of the slope relief can have occurred only after deposition of the Karewa boulder gravel prior to the next glaciation. Strong erosion during the second interglacial stage created a sharply entrenched valley that extended into the Karewa formation (pl. I, 2, and pl. XIX, 3). This relief making doubtless required uplift of the range, to which the Karewa lake beds responded by tilting of the boulder gravel (fig. 86). This uplift caused an extension of the mountain slope toward the Kashmir Valley (widening of the range through increasing amplitude of geanticlinal growth) and consequently extension of the valley. This phenomenon gives additional evidence for the great period of erosion which was deduced in the previous chapter from the relation of the third moraines to the Karewa relief. Hence the higher valley outlet existed prior to the interglacial uplift, but the lower one resulted from interglacial erosion. This explains why, contrary to expectation, the moraines of the stronger second advance terminate higher than those of the third glacier.

Terrace 1: Here, as at Zugu Kharyan, this interglacial stage was recorded not only by deposition of loam and by strong erosion, but by a terrace formation as well. This terrace (T1, pl. XX, 1) is the topmost in a sequence of five terraces which give to the Vishav Valley a singularly attractive appearance. In fact, it is here that the Pleistocene terrace system is developed to such perfection that we may well consider this a type locality for the entire Kashmir region (fig. 87 and pl. XX, 1).

In the descent from the even level of the Upper Karewa beds (7,525 feet) to the Vishav River, 1 mile south of Sedau, an upper terrace (T1) is encountered, 165 feet below the Karewa surface. From figure 87 it can be seen that this terrace forms a ledge, some 12 feet above the outcrop of the major boulder gravel. It is cut backward into Upper Karewa loam and bears an undulating relief, which is the result of younger surface drainage. Its true character is more clearly revealed on the right bank of the river, as plate XX, 1, shows. Locally its surface is covered with thin patches of gravel, but more commonly it is devoid of any deposits. Its origin dates back to a period of wide lateral planation following the drainage of the Kashmir Lake and prior to the entrenchment of the river. Quite obviously

this uppermost terrace succeeded the latest ice advance of the second glaciation, as its relation to the top boulder gravel indicates. The interglacial stream meandered freely upon it and was not sufficiently strong to deepen its channel. This does not, however, afford any clue as to the length of time involved in the lateral erosion, because the river then, as now, was braided as soon as it had left the rocky gorge from which it debouched, and in addition it encountered no resistance on the soft Upper Karewa beds.

The following phase of vertical erosion, on the other hand, must have required a longer effort, for not only is the slope beneath of considerable depth, but the Karewa gravel must have formed a strong obstacle to the down-cutting process. This led to the formation of a very deep valley, 240 feet below T1, which subsequently was filled up again by glaciofluvial gravel of later stages (fig. 87). The photograph (pl. XX, 1) shows that terraces 2 and 3 are composed of boulder gravel, which in places reaches the very bottom of the stream bed (G3). This illustrates clearly the effectiveness of the entrenchment that preceded the next ice advance.

Third glacier.—Terminal moraine: Along the forest path that leads from Sedau to the river ford below Kazanibal there is a peculiar moraine formation (fig. 87, TM3). It lies between T1 and T3, making a heap of large angular and faceted blocks, 297 feet above the stream bed and 110 feet below T1. The boulders are striated and rest in a sandy matrix. This moraine is banked up against bedrock and has an irregular pitted surface. A corresponding deposit was found on the opposite valley slope, but none was seen in the lower valley tract. Its position at the valley outlet is singularly suggestive of remnants of a terminal moraine that escaped erosion. The remaining thickness is about 30 feet. Interesting also is the complete lack of rolled or stained boulders such as compose the overlying Karewa gravel, and although the blocks are weathered no traces of heavy patination could be seen on any of them.

The peculiar position of this moraine on a slope high above T3 can be understood only if one looks across the valley, where a broad terrace (T2) is prominently displayed. This terrace is 15 feet below the bottom of the moraine and is developed on thick gray, coarsely stratified boulder gravel (pl. XX, 1, G3). At the valley outlet this formation carries erratic blocks on its surface, one of which measures 300 cubic feet. The appearance of ice-transported blocks at or a little above the terrace level T3 can only mean that a glacier advanced into the valley after the bulk of terrace gravel 2 had been deposited. Furthermore, the absence of large boulders below this region permits us to infer that this glacier had terminated hereabouts and that the boulder moraine, as well as the erratics, was dropped during a stage of ice stagnation. These considerations obviously support our view as to the existence of a terminal moraine between T1 and T3.

Terrace 2: The association of boulder moraine with a terrace formation near Sedau suggests that both deposits are closely related to each other. The slope exposure does not permit recognition of a clear contact, and therefore it is an open question whether the moraine was superimposed on the terrace gravel or whether the gravel was banked up against it. The occurrence of erratic blocks in the upper

layers of T3 on the corresponding slope would argue for superposition, as they could have been dropped only after the interglacial valley was filled up with gravel. Under such conditions the moraine would belong to a glacier which advanced to the valley outlet after refilling of the valley had taken place.

The nature of this terrace gravel (G3) is such as to indicate rapid accumulation of glaciofluvial outwash. Its components are well rolled, but there are subangular and locally even faceted boulders, which prove its relationship to an ice advance slightly older than that to which terminal moraine 3 belongs. Coarse gravels interchange with sandy layers, and the rapid change of facies signifies a fan, the total thickness of which amounts to nearly 200 feet. On the left bank this gravel overlies tilted Lower Karewa beds that dip 25° SE. Good exposures of this relation are found along the first river curve (pl. XX, 3) below T3. Farther downstream it can be seen that the Lower Karewa lake beds are conformably overlain by tilted fan deposits whose brown color contrasts with the light gray of the gravels of the third glacier (pl. XIV, 3).

We assign this second terrace formation to the third glaciation on account of (1) its position in relation to the Upper Karewa gravel, (2) its composition, and (3) its association with true morainic deposits. As indicated above, this glaciation apparently fluctuated. At first a major advance, of which no records are known, took place, but the following retreat stage is documented by the glaciofluvial deposits of G3. After this aggradation, the glacier once more moved downward and left terminal moraines near Sedau. During the second retreat a new gravel sheet must have been added to the former fill, and it is to this late retreat stage that we can assign the formation of T2. The third glacial gravel is thus of composite origin, yet on the whole it belongs to the third glaciation. This conception of a changing glacier front is fully in accord with the results gained from the discussion of the glacial records near Drang and Zugu, from which at least two, if not three, moraine ridges of the third glaciers were reported. In addition we must again refer to the analogous formation of a second terrace in the Sind and Liddar valleys.

Trough remnants in Harseni Valley: Upstream T2 can be followed beyond the wooden bridge at Kazanibal and it is here that boulder moraine is again encountered. Whether this represents a lateral moraine of the third glacier or a stage of glacial stagnation could not be decided. No observations were made in the gorge that leads into the Harseni Valley. One mile farther on, at Shahkut, there are two terraces, the upper of which is cut into Karewa clay (T1), while the lower forms flat remnants of terrace gravel (T2). Below Tsurugul Pass the older ground moraine filling (pl. XIX, 1, GM2) is dissected, and hence little is preserved of a trough valley such as might be expected from the other records. Yet on the right bank where the older moraines are denuded it is possible to recognize a slope profile reminiscent of a trough. About 2 miles upstream a flat trough is incised into bedrock, and simultaneously lateral moraines are encountered. Their position is 400 feet above the stream bed where they rest against ground moraine of the preceding glacier. Noteworthy is the fresh appearance of these boulder moraines, in contrast to the weathered condition of the second moraine. Their thickness is in excess of 60 feet

and decreases visibly the farther upstream one proceeds. In the narrow headwater region the trough form is more perfectly preserved than anywhere else (pl. XX, 2). This is because the valley is incised in bedrock, and in the bleak-looking chasm striated walls, over 100 feet above the floor, bear witness to the third glacial action.

A comparison of width between the upper and lower trough remnants shows the difference between the third and second glaciations (pl. XIX, 1). As at Tosh Maidan, the third glacier was considerably smaller in volume than the second; its thickness may have been 250 feet. The terminal moraine, however, lies about 2 miles beyond the hypothetical terminus of the second glacier and about 1,000 feet lower. This paradoxical relation can be understood only after due consideration of the preceding uplift and rejuvenation of the slope relief. In consequence of this uplift the third glacier followed a much steeper gradient, which directed its motion more effectively and caused the ice tongue to advance into the Karewa Hills.

Third interglacial stage.—Terrace 3: In the upper Harseni Valley there appears a terrace made of coarse subangular boulder gravel. Its position in the trough remnant of the third glacier (pl. XIX, 1, T), 60 feet above the stream, and the presence of large boulders suggest that it accumulated during a very late retreat phase of the ice. Whether this phase is to be considered as glacial or interglacial is a matter of convenience. Yet it is more likely that this gravel was formed when the glacier had retreated back to the uppermost valley position, which is only 4 miles distant, because with this position it had reached the status of a relict glacier characteristic of interglacial periods in this region. This does not necessarily mean that the terrace level is of equal age, because the snow waters must for some time have flowed across the gravel fill of the trough and they might then have leveled the outwash deposits. Additional information on the origin of this terrace is to be gained from the presence of another terrace that lies 20 feet below. This evidently belongs to a still later glaciation, which left moraines along the present stream bed. Hence the trough making of the older glacier (G3) was followed by a twofold terrace formation, of which the higher one is of third interglacial age. This relationship becomes much clearer in the valley outlet at Sedau.

The impressive array of terraces along the Vishav River is really made explicit by the third level (T3), because it is the widest and most prominent (pl. XX, 1). It lies 160 feet below T2, and at first glance it may be seen to represent another fill stage. Fortunately the river has cut obliquely into the underlying formation so that the inner terrace structure is exposed to full view. The photograph even enables us to recognize the thinning out of the terrace gravel below T3 toward the upper slope. The exposures also prove that the gravel below T2 is identical with that below T3. This must mean that T3 is the end product of a degradation to which we can assign not only the terrace level but the overlying slope as well. T3 was carved out of the glaciofluvial fill of the third glaciation and should therefore be of interglacial origin.

Terrace formation and settlements: The photograph (pl. XX, 1) shows on the surface of T3, near the upper slope, some light-colored fields. These are planted with maize, which grows abundantly only where the gravel is coated by loam.

Brown silty loam overlies T3 in patches, and as it is missing on the lowest level (T4), we assume that it accumulated in this interglacial period as river silt. The silt lends an aspect of fertility to an otherwise stony ground, and the Kashmiris have built their farmhouses on T3 for this very reason. This association of settlement, agriculture, and terrace formation is very characteristic of the outlets of the Pir Panjal valleys—in fact, it is so striking that one is induced to see in it a guide for the earliest settlers of Kashmir. These have left their traces all over the valley, especially in the megalithic site at Burzahom, near Srinagar, which is a settlement and monument of the Younger Stone Age. Use of polished tools by these people makes one speculate on the origin of these implements, and in this respect an interesting find must here be mentioned which may throw some light on the problem. On T3 was found a large erratic block (possibly derived from a higher level), on the smooth upper surface of which were seven elongated and highly polished grooves. The grooves are boat-shaped, 2½ inches deep, and placed in a row next to each other. On one corner of the block traces of pecking could be seen. very reminiscent of the method employed by prehistoric artists in the neighboring Punjab province. Taken together, these two phenomena suggest the inference that at some remote time people came here to polish stone tools, and as terrace silt and Karewa clays made agriculture possible, it is by no means far-fetched to assume that this region around Sedau was settled in prehistoric times. Indeed, the presence of an ancient historic bulwark on top of Sedauthur Hill, near Sedau, where the same type of pottery occurs as that found at Harwan (near Srinagar, third to fourth century A.D.), supports such a speculation, as it proves the antiquity of human settlements at the valley outlet.

Such associations should be of interest to archeologists who are concerned with the origin of neolithic agriculture in Asia. For if similar and more perfect relationships between terraces and prehistoric settlements could be found elsewhere it should be possible to elucidate the part which such associations have played in the evolution of human cultures in India.

Fourth glaciation.—The progressive shrinkage of the size of glaciers toward the end of Pleistocene time is nowhere more evident than in this region. To begin with, the terminal moraine (TMIV) is encountered at 8,863 feet, below the ford by which one crosses the Harseni River in order to get to Narilwein (fig. 85). This position is 1,200 feet above that of the third terminal moraine. It is an incompletely preserved ridge of large angular boulders which traverses the valley some 40 feet below the level of T3. Here knoblike masses of this boulder moraine are found on both banks, and some of them are 30 feet high. Below the moraine there are neither any glacial deposits nor any morphologic traces of a younger glaciation, whereas upstream lateral moraines abound. This situation makes us believe that this moraine (TMIV) is the lowest glacial deposit of this ice advance. The fourth glacier apparently never entered the gorge, and its total length was about 10 miles. Its thickness must have been under 100 feet, for that is the total height of the slope from T3 on downward, on which no traces of glacial action were found. Lateral moraines usually accompany the stream up to a height of 25 feet,

but on account of slope wash there is no sure way of telling how far up they had lain originally. A comparison of data relating both to the present glaciation of this valley and to the Pleistocene Harseni Glacier will show how extensive this latest ice advance was.

	Budil Glacier	Harseni Glacier
Glacier snout (feet)	11,600	TMIV: 8,760
Glacier height (feet)	110	>100
Glacier width (feet)	400	300–400
Glacier length (miles)	$1\frac{1}{2}$	10
Cirque level (feet)	13,400	13,000
Snow line (feet)	?15,000	?14,000

A terminal moraine wall intermediate between TMIV and the snout of the Budil Glacier (fig. 85) encircles a narrow lake in the valley floor at 11,085 feet and lies not quite 2 miles from the Budil Glacier. This moraine obviously marks a brief glacial advance of relatively recent date and should be considered of post-Pleistocene age. We will call this stage a fifth glaciation and designate the terminal moraines by TMV.

Here, as at Zugu Kharyan, the position of TMIV is about halfway between that of TMIII and TMV. Corresponding to the length of the fourth glacier, we find that its width must have been half if not one-third of that of the previous glacier. This can be computed from the distance between corresponding lateral moraines and the width of the valley floor. Whether all tributary valleys carried glaciers at this stage cannot be stated with certainty. Most of the tributaries have cut vigorously into the moraine-filled third trough, and in consequence no morphologic traces of the fourth glaciation were preserved. It is also very likely that it was the erosion of the third interglacial stage which caused the side streams to cut far back into the range, thereby shifting the ledge of the hanging valleys almost to the cirque region.

Terrace 4: A low terrace in the upper Harseni Valley lies 30 to 40 feet above the stream and is composed of very large subangular boulder gravel. This is mingled with coarsely stratified gravel, so that the fluvial nature is clearly revealed. The formation is unquestionably a glaciofluvial outwash of the retreat phase, but its correlation with terrace 4 of the lower valley remains undetermined chiefly because of the incomplete state of preservation of terrace 4 in the gorge above Sedau.

Terrace flats below T3 are generally not well preserved. The first one appears at the sharp river bend at the ford near Sedau. It lies 40 feet above the stream and is made up of rather coarse gravel with few large boulders. The surface is somewhat irregular, owing to low boulder ridges which mark ancient stream channels. A few boulders show facets, but others are wholly angular as if derived from slope débris. The pebble composition is more monotonous than in any of the older terraces. Amphibolitic and gneissic rocks dominate, reflecting the formational association characteristic of the watershed range. The total thickness is here 8 to 10 feet. On the left bank the contact of this gravel with the older terrace

formation of T3 is clearly exposed and, as expected, T4 is banked up against the slope below T3. This relation signifies the last aggradation of the Pleistocene river, and (for many reasons) it is likely that T4 is a product of that last glaciation. In support of this contention may be cited (1) the occurrence of faceted boulders; (2) the aggradational nature of the terrace, which is in conformity with the observations previously made at Zugu; (3) the position of the terrace level below T3 and its regional presence in the valley below the trough of the third glacier; and (4) the thinness of the gravel compared with the thick gravel fill of the previous ice advance. In regard to the fourth point, however, it should be noted that the thickness of a terrace formation need not be altogether proportional to the intensity of glaciation, for the erosional agency was dependent on uplift of the range as well.

From the thickness of terrace gravel 4 and its altitudinal position in relation to T3, it becomes evident that aggradation was preceded by erosion. This led to entrenchment of a stream in T3 which preceded the latest Pleistocene fill stage. In this process we may once more recognize the tendency to rejuvenation which, in spite of frequent checking by glacial action and intermittent crustal stability, is manifested throughout the Pleistocene. Because of the fact that the fourth glacier terminated many miles upstream from the valley outlet, it is probable, though by no means certain, that this erosion may have started during or immediately subsequent to the last ice advance. A long time may have elapsed before this valley became filled with outwash gravel, and for this reason it is better to refrain from too definite a statement on the precise age of the erosion.

Terrace 5: Below T4 another terrace level is found some 10 feet above the Vishav River. This also is made up of coarse boulders, yet the blocks are more water-worn and mixed with sandy gravel. Its terrace character might be questioned in view of its low position above the recent flood plain, of which it may be a part. Floods are frequent in this region, and they may at times even reach almost to the level of the terrace surface, but its vegetation (bushes and grasses) argues against this supposition. There is also no sign of freshly deposited gravel on top of T5. We are therefore inclined to consider it a low terrace remnant. This gravel rests against the slope below T4 and is derived from a more recent aggradation of the river bed. As it is analogous to the earlier deposits it can be assigned to the latest short glaciation, which is documented upstream by the high TMv.

Rimbiara Valley

Moraines on the interstream divide.—The Harseni and Rimbiara valleys are separated from each other by a high divide, which slopes gradually from 14,500 to 9,000 feet and less. It makes a broad shoulder, the relief of which was sculptured by preglacial and glacial processes. The second glaciation left an especially extensive cover of ground moraine along both flanks, which are grown over with forest and thick underbrush. Exposures, therefore, are restricted to gullies that lead down to the Rimbiara Valley, near Hurapur. One traverses these on the road from Tsurugul Pass to Hurapur (fig. 85).

One mile northwest of the pass, where the road crosses the Kankol River, there are several boulder ridges whose lobate forms suggest terminal moraines. They are restricted to the valley and at 8,800 feet form a steep slope across which the stream cascades through the forest (fig. 88). Half a mile downstream, Karewa clay is found resting upon slate rock, and a train of boulder moraine accompanies the river irrespective of this contact. This relation calls to mind the position which the moraines of the third glaciers occupy at the valley outlets. Indeed, the lateral moraine, for such it must be, can be followed all through this side valley until it reaches the Rimbiara River. Before reaching Hurapur one observes how the tributary breaks through a thick boulder conglomerate in which the Karewa gravel of the second ice advance is instantly recognized. The lateral moraine and its outwash products can be followed downstream almost to the confluence, a relation which fixes their age as post-Karewa. The Kankol moraine, then, lies 900 feet below the terminal moraine encountered upstream and, as the upper moraine can represent only the minor and last glaciation (fourth), it is obvious that the lower moraine must belong to a glaciation intermediate between the fourth and second advances. In other words, a small tributary glacier (third) descended this valley, but whether it reached the main valley is uncertain. From

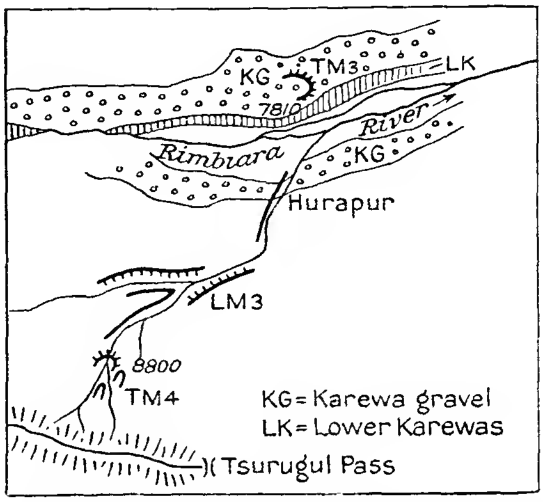


FIGURE 88.—Sketch map of glacial deposits at Hurapur in Rimbiara Valley. TM3, TM4, terminal moraines; LM3 lateral moraine.

FIGURE 89.—Generalized transverse section through Rimbiara Valley at Hurapur. U.K., Upper Karewa; TI, TII, etc., terraces; M3, terminal moraine; K.G., Karewa gravel; L.K., Lower Karewa; c.cgl., cemented conglomerate (first glaciation).

these observations it becomes clear that the interstream divide carries boulder moraines of two major glaciations (fourth and third) and, in addition, ground moraine belonging presumably to the second ice advance.

Karewa gravel.—The most striking feature in the physiography of this valley is a major gravel terrace which accompanies the river from Shupiyan upstream for a distance of 10 miles or more (pl. XIV, 2). Opposite Shupiyan its bold precipitous slopes rise 120 feet above the stream bed. Their surface is strewn with

coarse subangular boulders of brown patination. The section in figure 89 indicates that this formation occupies a large portion of the valley slope. It lies between Lower and Upper Karewa beds and accordingly represents the Karewa gravel. The structure of this formation is illustrated in figure 90. It indicates an increase of thickness upstream, from 25 feet to almost 300 feet, over a distance of 9½ miles. At once it becomes clear that this fan does not coincide with the valley outlet but that it is situated almost 10 miles upstream, thus indicating that the greatest accumulation of débris was caused by an agency not dependent on the river gradient. This agency was a major Rimbiara glaciation, for scratched and faceted boulders grow increasingly numerous upstream, and their size increases correspondingly. At the valley outlet near Balapur, as also at Hurapur, this glaciofluvial fan rests unconformably on Lower Karewa lake beds, and it is this direct superposition which fixes the age of the main terrace gravel as second glacial.

The thickness of this outwash fan points to a very strong glaciation, for we have every reason to believe that here, as in the Vishav Valley, the Karewa

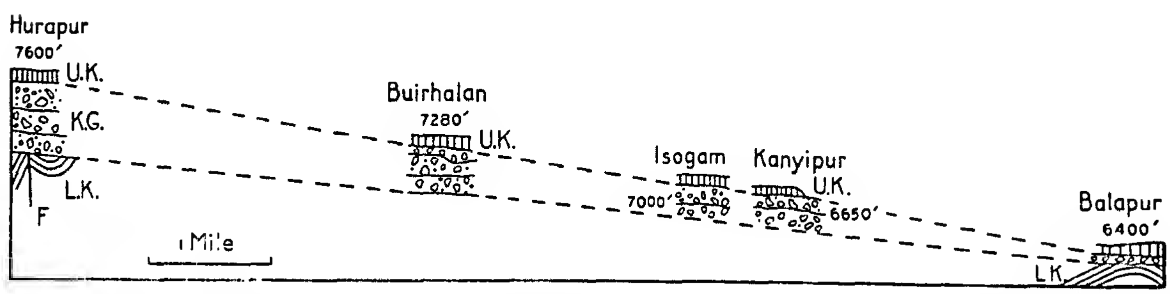


FIGURE 90.—Longitudinal section through Karewa gravel fan in lower Rimbiara Valley. F, fault; other symbols as in figure 89.

gravel merges into true ground moraines. The morphologic records of this second Rimbiara Glacier are still recognizable in the valley tract above Hurapur, where the upper slopes have a troughlike appearance.

Lower Karewa beds and earlier fan formations.—Dark- and light-gray lake clays underlie the major terrace formation and accompany the river upstream to Hurapur. Here their bold bluffs display the tilted structure so typical of this formation. The fine lamination of the clays and silts is undisturbed except in local regions where major faulting has caused a turbulent structure along slip planes. These normal faults are, to all appearances, major displacements antedating the second ice advance. Their origin is clearly connected with the orogenic movements to which the entire range was subjected at the end of the first interglacial stage. Of interest is the fine texture of these beds, in which the dark clays exhibit layers full of fresh-water shells. No coarse detrital matter disturbs the uniform lamination of the clays, the deposition of which doubtless was effected by a quiet body of water. If this was a lagoon of the larger Karewa Lake one would expect to find traces of a channel in which the interglacial river discharged its load on its way to the basin. The lack of such traces might be due to the incom-

plete preservation of the lagoon filling along the valley slopes and also to the denudation following the dislocations. The existence of varves in these beds, as reported by Norin (1925), is not incompatible with the age interpretation previously given. It has been pointed out that the earliest clay series of the Lower Karewa beds might have been formed at the end of the first glaciation, traces of which are to be seen 2 miles downstream from Hurapur. Here, on the right bank and close to the point where the road descends from the forested terrace to the valley floor, a patch of cemented conglomerate appears underneath the lake beds. This formation, in consistency and composition, is so dissimilar to the terrace gravel and later outwash deposits that it can be referred only to the earliest Pleistocene fan stage. The pebbles are well rolled and cemented with calcareous matrix so as to form a deposit similar to the conglomerate of Malshahibagh, near Gandarbal. We are inclined to refer it to a melting stage of the first glaciers, which would also account for the formation of varves in the lowest Karewa beds. Generally speaking, the significance of varves as indicators of glacial conditions has lately become less certain, through recent observations on varve-bearing postglacial formations of North America. It therefore seems advisable not to overemphasize the importance of varves in the Kashmir region until someone has investigated this problem in detail.

Terminal moraine at Hurapur and Rimbiara terraces.—Here as in the other valleys there are several terraces, the age of which is determinable from their relation to the glacial deposits of the second and third ice advances. In this respect a moraine opposite Hurapur is of special interest (fig. 89, pl. XIV, 2).[1] Here a bluff made of Lower Karewa beds displays a narrow syncline, some 600 feet wide, the western limb of which is down-faulted so that the silt and clay layers are sharply upturned to an angle of 80°. This faulted fold is unconformably overlain by brown Karewa gravel of great thickness, which builds up the lower valley slope. Against it there rests a boulder moraine that makes a clearly defined lobate ridge, the apex of which points to the valley center opposite the bridge (fig. 88). The boulders are slightly worn and rest in a sandy clay matrix which is much disturbed, as if the rock débris had been pushed together under pressure. Some of the blocks measure 20 feet in diameter, and many of them are faceted with striae preserved. As the moraine rests obliquely against Karewa gravel its thickness could not be determined. This moraine clearly marks a major stage of glacier stagnation, its structure pointing to a terminal push moraine of a Rimbiara Glacier that advanced after the slope formation in Karewa gravel was well matured. The time interval between the second and this subsequent advance therefore must have been long, a conclusion which is also supported by the fresh state of preservation of the boulder moraine. From the foregoing discussion of the moraines in the tributary valley, it can be concluded that this terminal moraine occupies an intermediate position between the higher moraines (8,800 feet) and the Karewa gravel of second glacial age. Accordingly, the third Rimbiara Glacier advanced to about the same level as its neighbor in the Vishav and Sokhnagh valleys.

[1] This moraine is discussed in a paper by Norin (1925), who gives it a younger age.

This third ice advance was preceded by the cutting of a terrace, which is preserved on the higher slope near the boundary of Karewa gravel and Upper Karewa silt. It was succeeded by the formation of another terrace (T_3) which lies about 500 feet beneath the surface of the Upper Karewa beds and 120 feet above the stream bed. As in other regions T_3 is the widest of all the terraces. Its greatest width (half a mile) was observed near Buirhalan, where it carries a terrace loam several feet thick. The relation of T_3 to the terminal moraine is sketched in figure 89. The river of this terrace eroded part of the moraine and was therefore younger than the third glacier. The terrace width and the presence here and there of a corresponding rock ledge testify to a prolonged period of degradation, which we can again refer only to the third interglacial stage.

There are two lower terraces in the valley outlet, the lowest of which is 15 to 20 feet above the river, probably corresponding to T_5 in the other valleys. The higher level is made up of a coarse boulder gravel, which appears to rest against Lower Karewa clays. It stands about 50 to 60 feet above the stream bed. Although it appears that the several terrace levels in the Rimbiara and Vishav valleys do not exactly correspond to each other (owing evidently to differences in erosive powers), it is evident that the Rimbiara River tract holds the same record of glacial and interglacial stages as the other valleys.

Region Intermediate between the Sokhnagh and Rimbiara Rivers

General physiography and structure.—The Pir Panjal slope in the area between the Sokhnagh and Rimbiara rivers displays a sharply dissected relief between 8,000 and 6,000 feet in altitude, in which five major streams have cut a good number of deep valleys. Most of these follow the gently sloping surface of the Karewa beds except for the northern branch of the Romushi River, which makes a longitudinal valley some 5 miles long. This curious behavior of the stream pattern presumably originated shortly after uplift of the Karewa formation, for the river follows a syncline in Karewa beds until it reaches the valley outlet. From here on the stream cuts through the Karewa structure and gains its full erosional power by confluence with the southern branch, so as to proceed in the normal slope drainage toward the alluvial flats of the Jhelum. Indeed, the anticline that borders this valley tract in the northeast makes a prominent ridge of sandstone and silt, thereby forcing the river to oblique deflection toward the outlet. This anticline must be the direct cause of the prominent elevation of the ridge (8,259 feet), which stands out as a topographic landmark in an advanced position along the foothills. With the exception of this local adjustment to structure, all the other streams make a perfect slope drainage of antecedent character, cutting at right angles through the Karewa folds.

As previously mentioned, the Lower Karewa beds exhibit in all these valley exposures a normal fold pattern in which the folding increases with approach to the range. Now, it cannot be mere coincidence that just here, where the Karewa folding was stronger than anywhere else, the foothills are higher than in other regions of the mountain front. On the contrary, it would appear that the higher

altitude and deeper dissection of this slope area constitute a true surface expression of the uplifting processes, accompanied by folding, to which this region had been especially subjected. This phenomenon had already been observed by Dainelli, but it deserves special emphasis in view of the repeated reference that is made to the youthful tectonic history of the Pir Panjal. This slope drainage, therefore, cannot date back farther than the end of the first interglacial stage, when the first folding took place, and it developed, presumably fully, only in the second interglacial stage, after deposition of the Upper Karewa beds.

Owing to the intense dissection of the soft Karewa beds, the relief is somewhat obscured by solifluxion, slope wash, and landslides. At many places I observed large portions of Karewa clay in a slipped or otherwise disturbed position, especially in the deeper valleys of the Dudhganga and Romushi rivers. For this reason it is impossible to find any coherent terrace system. Patches of terrace remnants occur at many places, as at Arigam, on the Shaliganga River, or downstream from Nilnag, west of Tsrar-Sharif (pl. XII, 3). At the latter place were found three distinct levels, the lowest of which lies 350 feet above the stream bed. These plain levels, however, are not terraces in the strict sense, but ledges formed through surface erosion on resistant sand or impermeable clay strata. These ledges dip with the beds and thereby contrast with certain even surface levels that appear at intervals on the higher valley slopes. These probably represent ancient river flats and generally lie 50 feet or so below the Karewa surface.

This Karewa surface makes a uniformly sloping relief and cuts across the fold structure of the beds. Its origin, however, is not clearly understood, for it must be remembered that the Upper Karewa beds covered part of the Lower Karewa beds, which in turn had been denuded prior to the second glaciation. It is possible that the surface was derived from an ancient level of post-Karewa age that resulted from a slow process of consuming through surface wash and river action. It is less likely to have been derived from an elevated uniform river plain, because no sure signs of river action have been found on any of the clearly exposed Karewa surfaces. A few pebbles are occasionally encountered on this surface, but it is generally possible to trace their derivation from a pebble-bearing silt or sand layer of the Karewa beds.

From the foregoing statements it can be seen that the possibilities of finding glacial records in this region are very meager. In addition, the area is covered with forest or cultivation, and good exposures are rare. However, there are a few places where moraines appear, and in the largest valleys of the Dudhganga and Shaliganga rivers the records are fairly complete.

Glacial features in the vicinity of Nilnag.—As the traveler approaches the elevated plain of Yus Maidan by way of Sangarwein, he encounters at 7,600 feet, 2 miles upstream from Nagbal, a boulder deposit. It makes low elongated ridges on both valley flanks, some 50 feet above the river, and is composed of subangular blocks of metamorphic and trap rock of foreign origin. No sure traces of glacial transportation could be detected on any of these boulders, but their position on top of Karewa silt and their derivation from the higher range give sufficient indi-

cation of glacial deposition. Their superposition on Karewa beds and the preservation of boulder ridges exclude their belonging to an earlier glaciation, and in view also of the higher position of the fourth moraines, it is most likely that this boulder deposit belongs to a moraine of the third glacier. On the right slope two separate ridges appear, which would indicate fluctuations of the ice close to the glacier terminal. This glacier must have been rather small and may have descended along the southern branch of the Romushi River, which has its source in the summit range of the Pir Panjal.

On the Yus Maidan proper no traces of glaciation were found, but their absence is easily accounted for by the lack of great valleys.

In the immediate vicinity of Nilnag, Karewa gravel appears unconformably on Lower Karewa beds at an altitude of 7,100 feet. The conglomerate is coarse, but the boulders are well rolled, indicating travel for long distances from the glaciated tract. Deposits younger than the second glaciation were not found here. Lake Nilnag is surely not of glacial origin but appears to have been dammed up by a landslide that temporarily blocked the passage of the river to the basin.

In general, it may be said that this region is poor in glacial records, undoubtedly owing to the absence of important drainage channels except for the upper Dudhganga and Romushi valleys.

Dudhganga and Shaliganga valleys.—The Dudhganga and Shaliganga rivers lie 4 and 6 miles, respectively, southeast of the Sokhnagh River and originate on the summit slope of the Pir Panjal.

In the upper reaches of the transverse valleys, especially between the slope of peak Tatakuti (15,500 feet) and Liddarmarg (10,600 feet), glacial débris forms an impressive mantle over Paleozoic and Triassic bedrock. Middlemiss (1910, p. 123) has described this landscape in his lucid way. He pointed out that lateral moraines, 500 feet thick, are encountered "several miles from, and 2,000 feet below, the present-day belt of live ice and active moraines." Apart from being covered with vegetation, "these vast superficial ice-formed accumulations appear to have hardly changed their original contours at all since first made." The upper portion of the Dudhganga Valley, called Sangsofed River by Middlemiss, is described as U-shaped and cut deeply into Panjal traprock. Of this 3-mile stretch Middlemiss says: "There are no moraines left along this reach (except a few scanty ones on the southeast side from hanging valleys), owing probably to the rapid retreat of the ice up it, and the subsequent scouring action of streams. There are, however, a few smoothened rocky hummocks testifying to the passage of ice over them." The thick lateral moraines mentioned by Middlemiss should belong to either the second or third glaciation. Their presence in the headwater portion of the Dudhganga Valley is important to an understanding of the glacial records in the lower valleys.

Less than 3 miles northwest of Nilnag the Dudhganga River leaves the mountains to enter the Karewa Hills. About 1 mile upstream from Brenawar morainic débris is encountered near the forest boundary. Although overgrown by grass and pine forests, these boulders have a fresh appearance, and their distribution seems

to follow the valley slopes. Their relation to the Karewa beds is not clearly exposed, but it seems as if these boulders do not go much beyond the forest downstream, a fact which induces us to date them provisionally as terminal moraines of the third advance. Their altitude at about 7,100 feet falls within the range of the general position of the third moraines on the Pir Panjal slope.

Downstream from Brenawar village as far as Nanhar, Lower Karewa beds are exposed in numerous bluffs. The upper valley slopes usually display a coarse boulder gravel, which cuts across the fold structure. Its brownish color and the occurrence of large, hardly rolled boulders signify the presence of the Karewa gravel. In the vicinity of Nanhar this gravel is little stratified and the boulders rest in a light-gray clayey silt matrix, so that the formation acquires the aspect of a redeposited moraine. As in the Vishav Valley the moraine character is lost progressively downstream. This again shows the change of facies so typical for the Karewa gravel: on the mountain border a lake moraine, redistributed in a shallow lake by river and off-shore currents, in which the fans are formed on top of folded Lower Karewa beds.

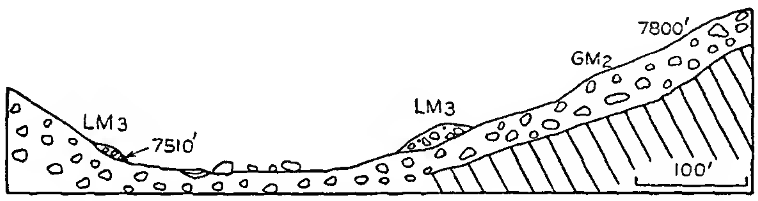


FIGURE 91.—Cross section through headwater branch of Shaliganga River above Guravet-Kalan. LM3, lateral moraine of third glacier; GM2, ground moraine of second glacier.

Terrace remnants are found on both valley slopes, but their preservation appeared to be insufficient for any analysis.

The Shaliganga Valley is of special interest in view of its being so near to the drainage of Tosh Maidan. Thick moraines appear in the Guravet Forest, some 4 miles upstream from Guravet-Kalan. At an encampment of gujars, called Pabblad Dan, the section shown in figure 91 is found.

The lower moraine (GM2) is a ground moraine which becomes several hundred feet thick upstream. Owing to weathering, the boulders have lost their fresh angular shape, most of them being subangular. This moraine covers practically the entire forested region and is even present on interstream divides which lie 400 to 500 feet above the floors of the valleys. Glaciation was evidently strong at this stage, and the foothills were apparently covered by some sort of piedmont glacier or a mass of ice formed by coalescent smaller ice tongues. This was, as has been more clearly demonstrated with reference to Tosh Maidan, the second glaciation—the time at which glacial growth reached its maximum in the Pir Panjal. A period of dissection and weathering followed during which a relief was cut into the Karewa Hills. Into the newly formed valley advanced another glacier which left moraines along the lower valley slopes (LM3). The boulders of these

moraines are fresher and angular, many of them showing signs of glacial wear. Huge erratic blocks on the valley floor testify to the magnitude of glacial transport during each of these stages.

The lateral moraine of the third glacier is found at 7,430 feet. It is well preserved and accompanies the valley upstream toward a broad forested depression into which the river is deeply entrenched. Downstream it is found in patches on both flanks as far as a stream junction at 7,190 feet. At this point there is a notable thickening of this moraine, so as to form a ridge through which the stream has cut a deep channel, choked with erratic blocks (pl. LV). Except for stray erratics, no true moraine is encountered beyond this point, the lower valley tract exhibiting only the older Karewa gravel. The erratics are strewn over the Karewa surface as far as Guravet-Kalan, or almost 1½ miles beyond the terminal moraine. Whether this should be explained by an earlier downward advance of the third glacier as far as this village or by the formation of a residual soil derived from the older Karewa gravel is a matter worthy of further study. In view of the absence of large erratics in the Karewa gravel, however, it would seem that the area of foreign boulders represents here an older and lower advance of the third glacier. The fan-like distribution of these erratics could thus be explained by a lobate widening of the glacier snout upon debouching on the Karewa Hills. Naturally this implies the existence of a glacial advance to as low as 7,100 feet, but it must be recalled that the neighboring third Sokhnagh Glacier also left a moraine at a similar altitude and that the third glaciation generally is characterized by two or three retreat stages.

Ferozepur Valley and Gulmarg Region

Ferozepur Valley.—The Tosh Maidan area is bordered on the northwest by forested country dissected by tributaries of the Ferozepur River. Up to a little over 8,000 feet the relief is undulating, yet minutely entrenched by numerous small streams which flow off northeast. In contrast to this the rocky slopes of Tosh Maidan bear traces of older and more mature land forms. These two physiographic units represent, essentially, two large chapters in the history of the region—namely, a pre-Karewa period and a younger period of lacustrine and eolian deposition. The younger period, as represented by Karewa silts, led to the formation of softly rounded hills and divides above which rises the boldly modeled floor of Paleozoic slate and trap rock. The relief superimposed on these land forms originated by glacial and intermittent river action.

As above demonstrated, the Tosh Maidan plateau remnant carries a complete record of the glacial history. This was substantiated by a survey of the Ferozepur Valley, to which I made repeated visits from the hill station of Gulmarg and from Srinagar.

Taking the path which leads from Tosh Maidan by Basam Gali Pass (12,100 feet) down into the southern headwater branch of the Ferozepur River to Pejan-pathri, one encounters lateral moraines on both valley slopes (fig. 80). South of the pass these moraines lie about 200 feet above a small troughlike valley, belonging,

presumably, to the fourth glaciation. Figure 116 gives the arrangement of troughs and moraines in this region. (See Paterson's section on traverse of high Pir Panjal to Poonch.) The pass lies at the bottom of a wide glacial trough, which, by analogy with the watershed glaciation of Tosh Maidan, should belong to the second ice advance. The cirque that lies 600 feet below corresponds to a similar feature on the south side of Basam Gali, where its origin was explained as being derived from a later glaciation (the third). This cirque is filled with large angular boulders of local derivation. From it two kinds of moraines emerge, a thick ridge-forming lateral moraine and a thin boulder moraine. The latter adheres to the recent stream bed, but the former clings to the higher slope, and farther downstream it can be seen that this is the lateral moraine of the third trough. Hence, the cirque was reused during the fourth glaciation, which may account for the thick accumulation of débris in it. Remnants of lateral moraine, 10 feet high, occur at the stream near the first important river junction, but they disappear with the trenching of the youngest trough. The U shape of this trough is preserved in hard bedrock, and it measures little over 200 feet across. Most prominent in this region is the third trough with its lateral moraines lying 700 feet above the stream bed. Its age relationship is always clear from its intermediate position between the lowest trough and the higher slopes covered by boulder moraines. These are residual ground moraines from which the clay and silt content has largely been washed out, with the result that large angular or subangular débris remains. Most likely frost action and nivation have also played an important part in the formation of this boulder deposit. It is identical with the débris found on the higher slopes of Tosh Maidan, a characteristic deposit for the region once scoured by the second glaciers.

Traces of a weathered and thinner moraine were observed by Paterson on his traverse from Kashmir to Poonch (see p. 196), which led him across a pass close to Basam Gali. These traces are found only at altitudes of 13,500 feet and above, hence they probably represent residual moraines of the first Pir Panjal glaciers. At Pejanpathri there is a wide, now abandoned cirque with a very coarse boulder filling that defies any identification. The high level spurs projecting from both valley flanks in this area are covered with similar block detritus. Already here the river flows in a gorgelike valley, 800 feet deep, from which glacial deposits have largely been removed. But on the right upper slopes in the vicinity of Buna Danvas a new formation is encountered. Bedrock and boulder detritus are here veiled by brownish colored silt from which patches of subangular gravel are weathered out. The silt is structureless and at once brings to mind the Upper Karewa zone 4, the eolian origin of which has been discussed. The high altitude (9,700 feet) of this deposit also argues for eolian origin, an interpretation which is supported by the presence of fossil soil profiles in the upper 10 feet. The coarse material locally found embedded in this silt may be derived from slope wash or solifluxion.

A mile to the northwest lies the junction of the Bahan and Ferozepur valleys. The relation between the wide moraine-covered second glacier floor and the narrow U-shaped valley of the third glacier found at this place is sketched in figure 92. The lateral moraines rest on slate rock, which is striated. The high leveled spur

above displays hillocks made of coarse boulder moraine. This ancient glacier floor can be traced downstream for 2 miles, and at Allazabad it carries weathered ground moraine which makes for a fertile meadow below Khelanmarg. Its boulders consist of trap, schist, greenish quartzite, slate, and quartz derived from the Paleozoic formations of the higher Pir Panjal.

Ferozepur terraces.—In following the valley path downstream, two gravel terraces are encountered on the left bank above Goran (fig. 93). The higher terrace is at places 150 feet wide and lies 95 feet above the lower terrace. It is cut into a thick boulder moraine that rests against the slope of the lower trough. Unquestionably this is a ground moraine belonging to the third glacier, which dates the upper terrace as third interglacial. Below (fig. 93) stratified glaciofluvial gravel lies upon a striated rock floor. This formation contains blocks as long as 50 feet, and it shows a dissected surface due probably to stream action at a closing period of a fill stage. The presence of faceted boulders and the aggradational nature of the terrace indicate, as in the other valleys, a period of rapid filling under glacial

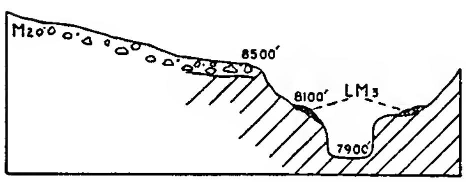


FIGURE 92.—Cross section through left slope of Ferozepur Valley at junction with Bahan stream. M2, moraine of second glacier; LM3, lateral moraine of third glacier.

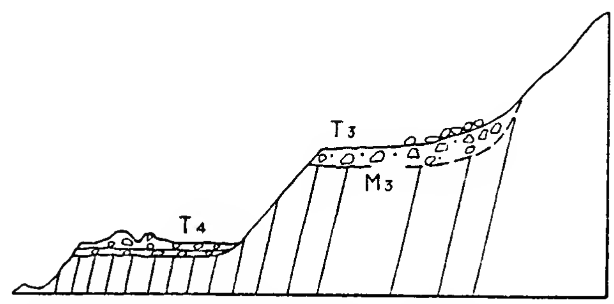


FIGURE 93.—Lowest two terraces in upper Ferozepur Valley above Goran. M3, ground moraine of third glacier.

conditions which we refer to the fourth advance. Corresponding terminal moraines (IV), from which this gravel may have been derived, may be expected a few miles upstream, above the river junction, where there is a nick in the stream profile caused by boulder moraine.

Terraces 3 and 4 are also well exposed at the bridge above Drang (fig. 94, pl. XXI, 1). The village, standing amidst maize fields, is surmounted on the right bank by a high terminal moraine (TM3) from which erratics and faceted boulders have been washed down to the terrace. This moraine (M3, pl. XXI, 1) lies 700 to 1,000 feet below the second moraines mentioned above and clearly indicates a major retreat stage of the third Ferozepur Glacier. T3 is cut into it and makes a wide terrace with a few feet of loamy silt on top. In view of the extension of T3 upstream, its origin must fall into a late retreat stage of the ice, when the glacier snout lay several miles above its previous terminus at Drang. Just above the upper houses of this village, adjacent to the terminal moraine, are clear traces of a higher terrace. Its gravel is exposed along the upper slope of T3 for over a mile. In contrast to terraces 3 to 5, this higher terrace terminates at TM3. Also the gravel is similar in composition and state of weathering to the moraine, so that there can

be no doubt as to the homotaxial nature of these formations. From these observations it would appear that the valley was filled with outwash material as much as 120 feet thick and that the interglacial river degraded this formation, thereby forming T3. This terrace makes a slope, 50 to 60 feet high, toward T4, which lies 20 feet above the stream bed. Terrace 4, however, is clearly presented only on the left bank, which accounts for its absence in figure 94. On the other hand, a lower

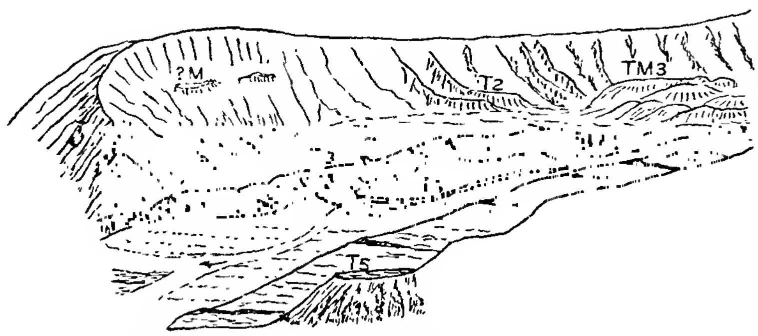


FIGURE 94.—Ferozepur Valley at Drang, showing relation of second wide-scooped trough to later glacial deposits. M, third moraine.

level (T5) is present on both banks and can be followed downstream, where its gravels are exposed on the left bank near the valley outlet. This gravel is banked up against the higher boulder-bearing terrace (T4) in the same way as near Sedau. Its thickness hardly exceeds 10 feet, not counting a few feet of loamy silt which spreads over both the lower terraces.

At Tangmarg the Ferozepur River debouches into the valley basin, where it has cut a funnel-shaped delta into the Karewa and glacial formations (pl. XXI, 3).

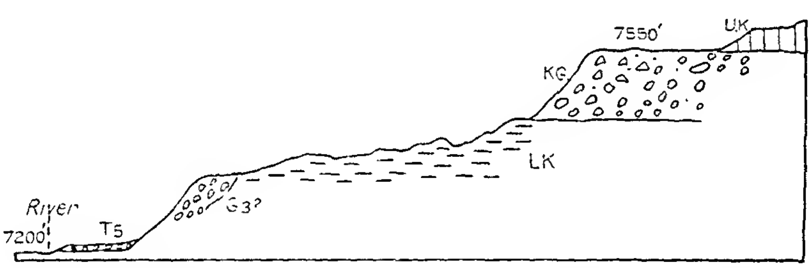


FIGURE 95.—Cross section through left slope of Ferozepur outlet above Tangmarg. T5, terrace; G3, third glacial trough; L.K., Lower Karewa beds; K.G., Karewa gravel; U.K., Upper Karewa beds.

Figure 95 gives a section through the left slope a quarter of a mile above the post office of Tangmarg. The main road was constructed on a ledge (7,550 feet) formed at the boundary between Karewa gravel and Upper Karewa silt (pl. XXI, 2). This ledge corresponds to the terrace remnant described from the Vishav and Sokhnagh valleys, where it was called T1. Its level is here 310 feet above the stream, but its inclination toward the basin is so strong that 2 miles downstream it reaches the upper limit of the basin. On this tract the Karewa gravel fan is perfectly

exposed, owing to the active cutting of an older Ferozepur channel, which was subsequently shifted southward to the opposite side. At Ferozepur similar bold bluffs appear, bringing to view the boulder gravel and the terrace on its upper limit. Apart from the terrace ledge mentioned, traces of a lower river level are found some 60 feet above the irrigation canal above Tangmarg. Here appears another gravel, in a somewhat fresher state of preservation (fig. 95), which seems to rest against the Karewa slope. It carries good-sized boulders in a matrix of gravelly sand, much like the terrace material underlying T3. The exposure, however, is not sufficiently clear to allow definite correlation with the outwash gravel of the third glacier.

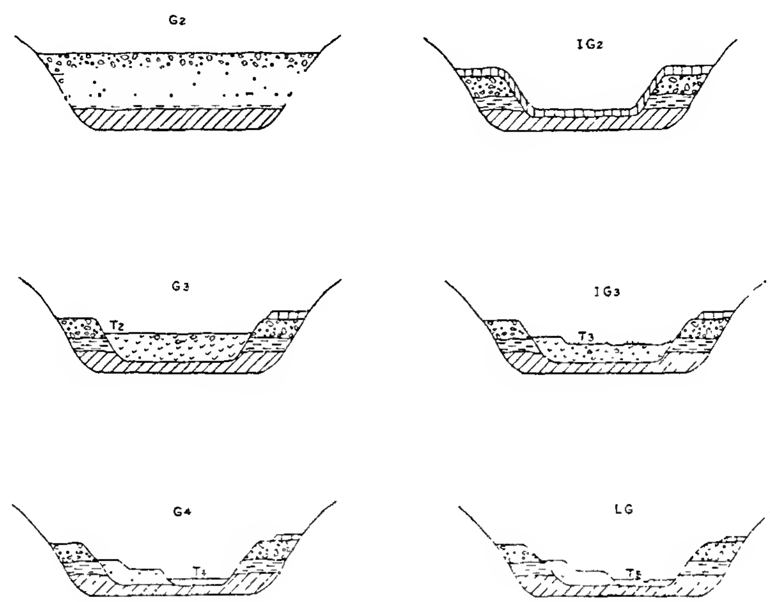


FIGURE 96.—Schematized history of Ferozepur Valley from second glaciation to postglacial time. G2, G3, etc., glacial deposits; T2, T3, etc., terraces; IG2, IG3, interglacial stages; LG, late glacial.

Loessic loam on river terraces.—Upper Karewa silts are well exposed on the main road below Tangmarg. They are brown and show layers of dark soil, giving the formation a well-stratified appearance. The carbonaceous matter in the soil layers is so rich in conifer pollen that one cannot doubt their eolian origin.[1] It must be admitted that this interpretation does not guarantee the exact age of the Upper Karewa beds, and in such sections one might feel inclined to refer these wind-blown silts to a younger period of loess deposition. Indeed, the occurrence of loessic loam on several of the Pir Panjal terraces is sufficient indication for a varying age of these eolian formations.

In order to clarify this question it is essential to sketch briefly the history of the Ferozepur Valley from the time of the second glaciation to subrecent periods. In the first schematized cross section in figure 96, G2 shows the trough

[1] From the same zone is derived sample M32, for which Wodehouse (Wodehouse and De Terra, 1935, p. 5) made a pollen analysis. See also Krynine's report on Karewa lithology.

of the second Ferozepur Glacier, filled with boulder gravel (derived from moraines), overlying Lower Karewa lake beds. After dissection, Upper Karewa silt was laid down as a mantle of loess (IG2). In contrast to the Himalayan slope no sure traces of lacustrine Upper Karewa silts appear in these sections, a lack which may be due either to intermediate denudation or rather to the high altitude of the valley outlet above the level of the early Upper Karewa lake. While no clear records of T1 are found, it is probable that at one time during the second interglacial period an upper terrace formed, as is evident from other valley profiles previously described. Through the interglacial valley (which had undergone uplift) the third glacier advanced, and as its snout lay nearly 2 miles from the valley outlet, it filled the lower tract with outwash gravels (T2 in G3). After this aggradation the river degraded, the glaciofluvial stream thereby cutting a prominent slope above a wide stream bed (T3 in IG3). This floor was mantled with a thin veneer of silty loam, distinguished from the Upper Karewa beds by its clay content. During the last glaciation of the upper valley portion, non-boulder-bearing gravels were laid down at a lower level (T3 in G4) and again a few feet of loamy silt were spread across the valley floor. Finally, in postglacial time (LG) the river deepened its channel, and from this resulted the lowest terrace (T5), of which only meager remnants are present.

From the association of the younger loam with the lower terraces it is evident that this deposit is younger than the Upper Karewa loessic silt. Although it is possible that the loam on T3 is derived in part from a redeposition of Upper Karewa material, its formation seems to have been connected with a stage during which the stream was able to carry only fine sediments in suspension. Hence the terrace loam marks a low-water stage at which dry climatic conditions had reached their optimum and at which the river was meandering freely across the valley floor. As in other glaciated and periglacial regions, it must remain an open question whether such terrace loams are generally derived from rewashed loess. In view of the frequency of dust storms in this area it is probable that loess was deposited in varying degrees throughout Pleistocene time and that the geologic record of this process reflects only optimum conditions of wind transportation and of fluvial deposition.

Gulmarg region.—Beyond a low divide northwest of the tract described above and 1,600 feet above the Ferozepur Valley lies the headwater portion of a tributary of the Ningle River, which is the last of the prominent slope drainage lines before one reaches the Jhelum Gorge. Dainelli (1922, p. 567) has pointed to its peculiar physiography, to which the alpine summer resort of Gulmarg owes its reputation. Perched high above the Kashmir Basin and situated at the foot of Apharwat Peak (13,592 feet), its undulating slopes provide ideal conditions for winter sport, and in the summer grassy flats and pine forest afford a diversity of recreation not easily matched by any other place in India. But the meadow character of Gulmarg (meaning "meadow of flowers") conceals many features interesting to the geologist, and good exposures are rarely found. It is therefore essential first to study the glacial history of this region on the higher slopes of the range.

At Khelanmarg, which lies 2,000 feet above Gulmarg (8,569 feet), a flat remnant of the old mature relief is preserved. Seen from a distance this place looks like a ledge on the steep mountain slope, and on account of its high altitude (10,500 to 10,800 feet) it may well be referred to the alpine zone of the Pir Panjal. At such altitudes nivation and solifluxion are very active, for the region is snowbound for 9 or 10 months of the year. This situation accounts for the monotonous cover of boulder trains and pseudomorainic débris, which defy geologic classification. Apharwat Peak sends large streamers of boulder débris down to the ledge, where the finer silt and clay matter accumulate to form a brownish-stained loam from which angular blocks weather out on the surface. This then is a typical solifluxion deposit of the alpine zone.

Moraines of the fourth and later ice advances.—At one time, however, Khelanmarg was ice-covered, and a glacier descended, or rather catapulted, down the 2,000-foot slope to the brim of the Gulmarg depression, where boulder moraines

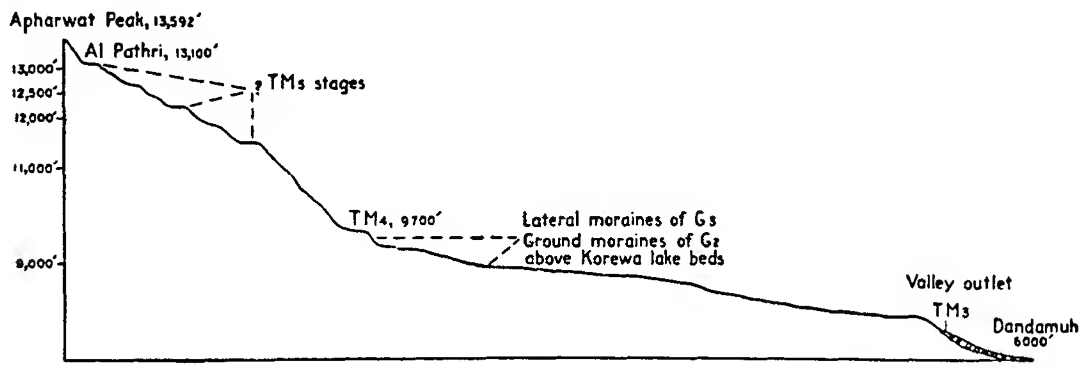


FIGURE 97.—Longitudinal section of upper Ningle Valley. TM5, TM4, etc., terminal moraines; G3, G2, third and second glaciers.

are found at contour of 9,000 feet. They are exposed along the Khelanmarg road about 200 feet beyond the last huts. Here streamlets have dissected a disorderly mass of débris in which large erratics occur. The erratics are derived from the higher region of Apharwat and their presence therefore cannot well be explained by local solifluxion. Also the altitude of this moraine is analogous with that found above the junction of the Ferozepur and Bahan rivers, so that I am inclined to refer it to the last major glaciation. This moraine apparently marks a halting stage of the fourth glacier above the Gulmarg basin. At this time this basin obviously was not glaciated.

The fourth moraine extends through the forest into the upper Ningle Valley, where it merges into large fans that descend a quarter of a mile west of Nagian (fig. 97, TM4). Farther northwest, at the stream junction of Liangmarg, a boulder ridge 110 feet high (9,700 feet) crosses the valley transversely. This marks a halting stage of the main Apharwat Glacier, whose deeply scooped cirque is now occupied by Al Pathri Lake (13,100 feet).

From this point emerge lateral moraines, which accompany the stream for some distance. The absence of any glacier or firn in the high region emphasizes

the great changes in the position of the snow line which must have occurred after the Apharwat Glacier advanced 5 miles to the upper Ningle Valley. The retreat of this and of the slope glacier above Gulmarg is marked by intermediate moraines and small terracelike flats, to which Middlemiss (1910, pp. 131–132) has already referred. One such retreat phase is recorded in a boulder ridge (10,000 feet) at the edge of Khelanmarg, and a terminal moraine seems to dam the cirque lake, Al Pathri (Middlemiss, 1910, p. 132), indicative of a very late phase of post-Pleistocene glaciation (fig. 97).

Records of earlier glaciations.—The Gulmarg region and the adjoining Ningle Valley disclosed a deal of information on earlier glaciations and interglacial stages which corroborates the conclusions drawn from observations described above. Dainelli (1922, pp. 568 ff.) had assumed that this headwater region had carried a glacier which moved from Apharwat Peak down to the Ningle Valley. A clay moraine, 30 to 50 feet thick, is exposed along the banks of the stream near the point marked "P. 8659" on topographic sheet 43 T/8. Here boulders of slate, trap, serpentine, and amphibolitic rocks lie in whitish clay, and the formation is overlain

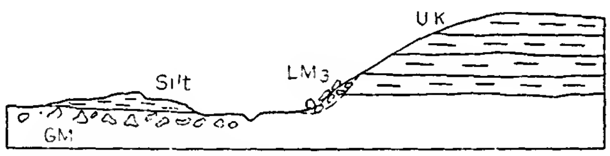


FIGURE 98.—Exposure of glacial deposits and Upper Karewa beds between Gulmarg and Dobi Ghat. GM, ground moraine; LM3, lateral moraine of third glacier; U.K., Upper Karewa.

by laminated silt. A few hundred yards downstream erratic blocks lie in the right slope some 30 feet above the river, and toward Dobi Ghat they appear in increasing numbers until a regular boulder moraine is formed, which follows the now deeply entrenched river. Both the slope position and the independent distribution of these boulders from ground moraine and silt (fig. 98) argue for a relatively narrow ice stream which moved across previously glaciated terrane to the Ningle Valley. It is difficult to say whether all three glacial deposits belong to one and the same glaciation. The boulder clay has not the usual weathered appearance of the second moraines, and, as the latter are characterized by large patinated débris on the higher flanks of the Ningle Valley, it is more likely that all three deposits belong to the third glaciation. If so, the laminated silt would mark the temporary ponding of glacial run-off between two minor ice advances.

Above these glacial deposits at Gulmarg lie Karewa beds which especially mantle the northeastern slopes. To them the valley owes its undulating surface. At Tilwanmarg their thickness exceeds 100 feet, and here they consist of laminated ocher-colored silt underlain by bluish-gray clay with plant remains. At the very top lies a brownish silt with dark soil bands analogous to the Upper Karewa beds near Tangmarg. This silt is underlain by lacustrine silts (plant-bearing) and clays, reminiscent of beds 3 and 4 of the Lower Karewa sequence. The occurrence

of such lake beds at 8,800 feet, near Gulmarg, is not surprising, considering the greater altitude at which this formation was found at Liddarmarg. On the other hand, it is interesting that the younger silt with soil structure is found 1,500 feet above the foothills at Tangmarg. This evidently supports our contention of the wind-borne nature of the topmost Karewa beds, for were these of lacustrine derivation, it would be very difficult to account for their varying position without as-

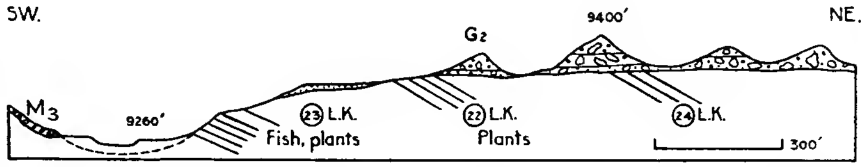


FIGURE 99.—Second glacial outwash and tilted Lower Karewa beds in upper Ningle Valley. M3, moraine of third glacier; G2, deposits of second glacier; L.K., Lower Karewa beds; 22, 23, 24, fossiliferous horizons.

suming great displacements for these young eolian deposits, for which no structural evidence is at hand.

Glaciations in the Ningle Valley.—About 3 miles to the northwest, in the upper Ningle Valley, another patch of Lower Karewa beds was encountered (fig. 99). This exposure has already been described in the section on Karewa lake beds, and mention was there made of the tilted position of the fossil-bearing zones. It was assumed that the overlying gravels were outwash deposits of a second glacier, accumulated during its retreat stage. This deposit is marked by worn boulders and pebbles in a sandy silt of medium-brown color. The boulders vary in size

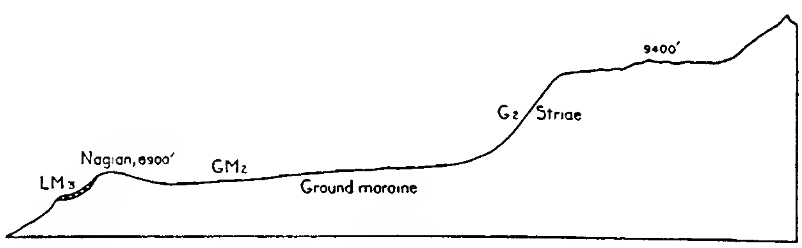


FIGURE 100.—Transverse section through right slope of Ningle Valley at Nagian.

(from 10 to 100 cubic feet) and form four low ridges which follow one another successively, parallel to the slope, over a width of 900 feet (fig. 99). A coarse bedding can be faintly recognized. The hummocky topography is clearly of depositional origin, for there are no traces of later stream erosion which might account for the parallel arrangement of these ridges. The rolled condition of the boulders, on the other hand, and their distinct alignment along the slope, indicate that they are ice-contact deposits laid successively against a gradually shrinking cake of ice which occupied the valley center. On the opposite side appear similar gravel ridges in which the débris is equally rolled and patinated. This formation lies 130 feet above the stream bed and is succeeded on the higher slope by coarse

angular débris with clay matrix. In it were found, on the path near Nagian, striated and faceted rocks. This moraine is of considerable thickness (300 feet at least), and it covers the entire higher tract, especially between contours 9,000 and 10,000 feet, extending across a flat divide which separates the upper Ningle tract from the neighboring headwater portions of various rivers which flow to the Jhelum and to the Kashmir Basin. It was also encountered at Linyanmarg, 2 miles upstream from the section shown in figure 99, where it is clearly limited to a wide, ancient valley floor. In composition and state of weathering this moraine is very much like the second moraines of Tosh Maidan, and its mode of distribution is also the same. As has repeatedly been stated, the second glaciation of the Pir Panjal was by far the most extensive, as is reflected in the great thickness and extent of the moraines and the width of the glacial troughs. As a result of coalescence of glaciers, these moraines transgress the lower divides, and it is this characteristic which argues most strongly for their second glacial age.

In addition, their association with a wide trough fixes their position in relation to younger moraines. This is illustrated at Nagian where a wide trough is filled with ground moraines (GM2, fig. 100) and dissected by the Ningle River, through which a later and considerably smaller ice stream moved, as indicated by a later moraine (LM3). The second Ningle Glacier (G2) was at one time some 500 feet thick at Nagian and scoured the flat trough, remnants of which are found also on the left slope near Atar. At Nagian, where it moved across a mature relief, its width must have exceeded 1 mile, but in approaching the slope it narrowed to about a quarter of a mile. Here its records have largely been destroyed by subsequent trenching of the lower valley. If we take into account the heavy ice cover during the second ice advance and the position of the ice-contact gravels in the upper valley, it would appear that these gravels belong to a very late retreat phase of the glacier. The glacier snout probably lay at 9,400 feet, and the ice must have remained stationary for some time, owing to the small valley gradient.

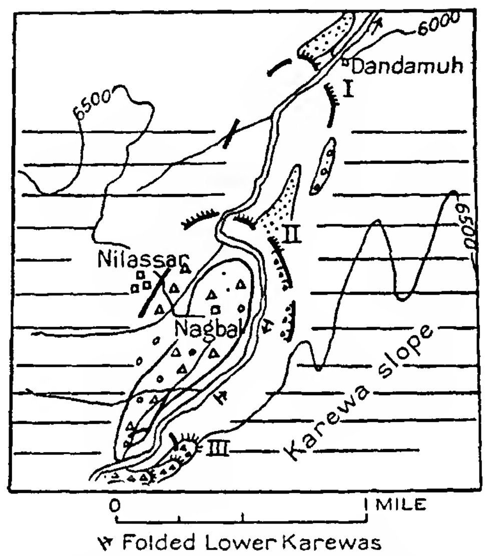


FIGURE 101.—Sketch map of morainic landscape at Nagbal. I, II, III, glacial deposits.

As figures 99 and 100 show, a younger ice advance is recorded by lateral moraines (LM3, fig. 100) which faithfully follow the slopes of a valley incised in ground moraines. Their height above the stream increases downstream in proportion to the deepening of the valley. At Bota Pathri (9,400 feet) they are 60 feet and at the valley outlet above Nagbal about 300 feet higher than the valley floor. This glacier was about one-third the size of the second glacier, and its course was defined by the relief cut previously into older moraines. The entrenchment of the interglacial stream in the slope region amounted to over 1,000 feet, to judge from

the difference in altitude between the floor of G2 and younger moraine remnants. Most of this erosion doubtless took place in the second interglacial period, which was a long interval, as has been shown.

Morainic amphitheater at Dandamuh.—At the valley outlet near Nagbal this second interglacial erosion is represented by a deep dissection of the Karewa beds (fig. 102, A) amounting to some 400 feet. It is this valley through which the third glacier passed 2 miles downstream, as far as Dandamuh (6,000 feet), where lies its terminal moraine (fig. 101). This makes a boulder ridge, 160 feet high, composed of large blocks (over 100 cubic feet) some of which were washed down the frontal slope and scattered across a terrace. This terrace is cut into the moraine and into a glaciofluvial outwash apron spread in front of M3. A few

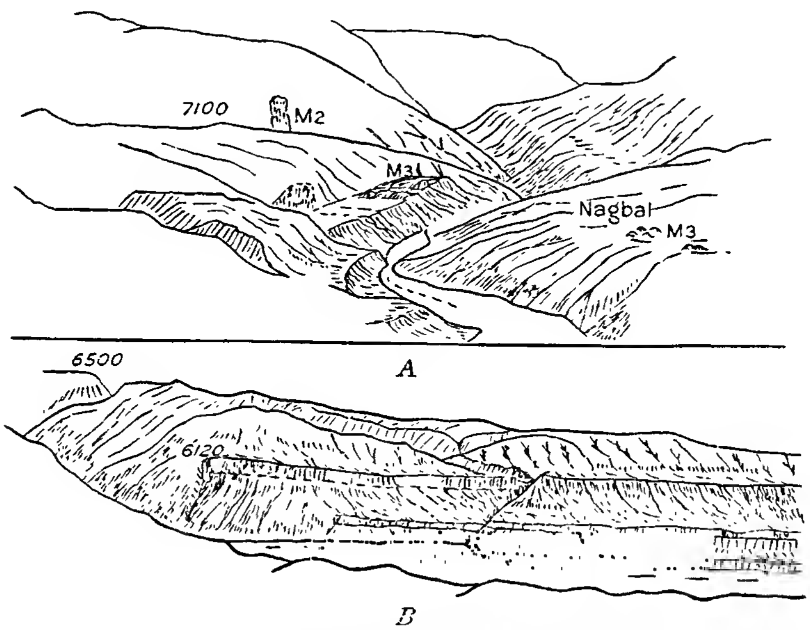


FIGURE 102.—A, Outlet of Ningle Valley near Nagbal; B, Terraces on Karewa beds above Dandamuh. M2, M3, moraines of second and third glaciers.

hundred yards upstream the moraine appears on both valley slopes, and it can be followed for little more than half a mile to a hamlet called Satar Siran. Here lies a second boulder ridge, less high than the former but equally prominent, owing to its large erratics and faceted débris. Its altitude is about 300 feet higher than that of the first terminal moraine. The stream is here diverted for 2 furlongs into a northwest-southeast course and thus follows faithfully the inner curvature of this moraine (fig. 101). The large lobate shape of this ridge becomes evident after we have plotted the erratic boulders on the left slope below Nilassar. These are scattered but condense conspicuously near this village, so as to form a low boulder ridge about 6 furlongs in diameter. Its inner relief is dissected by two streams descending north and south of Nagbal village. At their confluence with the Ningle River dark-gray laminated clays are exposed, making a high vertical bank.

These are Lower Karewa beds, which appear also on the opposite bank, where they display synclinal structure. The upper edge of the embankment is here formed of a coarse gravel with shingle structure which cuts across the underlying lake beds. This formation is only 9 feet thick but is composed entirely of rolled débris of trap and metamorphic rocks, suggestive of long transportation from the upper valley tract. In it we recognize a much reduced remnant of Karewa gravel. Its small thickness resulted, undoubtedly, from the scouring effect of the third glacier, which passed through the dissected fan of Karewa gravel.

The left slope is covered with subangular boulders, and a few true erratics of enormous size lie at random on the Karewa silt. About 2 furlongs from the rocky gorge through which the river discharges in a waterfall there appear, on the right slope, elongated boulder ridges composed of angular débris 110 feet thick. Their steep slope downstream, their topographic prominence, and the wealth of striated boulders suggest another halting stage of the same glacier. This terminal moraine (M3 on fig. 102, A) lies 200 feet above that of the second phase and apparently marks the third retreat stage of the third Ningle Glacier. Slope wash in the Karewa Hills covers most of the intervening ground between the two upper moraines. Higher on the right slope, above 7,100 feet, the valley flanks are covered with boulder moraine which has the same composition as that found upstream at Nagian (GM2, fig. 100).

Three terraces were observed in this section (fig. 102, B). The topmost lies about 210 feet above the stream bed and terminates at the outer slope of the second moraine ridge. It appears to be coextensive with the outwash apron mentioned above and therefore might be T2. A second terrace, some 85 feet above the river, is cut into the older gravel fill and into the two lower terminal moraines (T3). It is well exposed below Dandamuh, where the terrace succession is most clearly developed as sketched in figure 102, B. T3 can be followed several miles downstream until it finally disappears under Karewa landslide and slope-wash deposits. The lowest terrace makes a low bench on coarse gravels 20 to 30 feet thick. Its position in relation to T3 is not clear but might well be the same as that of T4 to T3 in the other valleys.

High on the slopes lies a boulder gravel of brown patination in which the Karewa gravel is recognized. Here again it would appear that the third glacier advanced several miles beyond the limit of the second glaciation, notwithstanding the fact that the second was of much greater intensity than the third. This apparent discrepancy in the behavior of the two glaciations is discussed below, but here it should be noted that the third glacier advanced in a much narrower valley than that which its predecessor had occupied.

Moraines at Dangarpur.—About 3 miles northwest of Dandamuh a slope stream is encountered which descends from the region adjacent to the upper Ningle Valley. At 9,000 feet, about a mile downstream from Tre Naran and just before the river enters the deep gorge at the forest limit, it breaks through a lobate ridge of boulder moraine. The conformity in altitude between this moraine and the fourth terminal moraine near Gulmarg is so striking that they may readily

be classified as belonging to the same glaciation. Indeed, the slope gorge terminates at this very point and is followed by a shallow valley, the lower slopes of which are locally strewn over with coarse gravel and boulders. A small ice tongue moving through this flat valley must have found it difficult to descend into the gorge without breaking loose from the main glacier at the nick of the gradient. It will be recalled that a similar condition prevented the last Sokhnagh Glacier from descending beyond the border of the Tosh Maidan plateau. This relationship between the fourth glaciation and the elevated mature relief of Pir Panjal is very striking and supports our contention as to the relative weakness of the last glaciation, which was restricted to the little-dissected region above the main mountain slope.

From the outlet of the gorge downstream toward Dangarpur (1 mile) the stream breaks through hummocky ground made of rock, débris, and clay. This formation might at first be taken for a landslide deposit were it not restricted to the valley flanks, where it builds narrow ridges. Some 600 feet above the first stream junction at Dangarpur lies a moraine wall at 6,320 feet (pl. XXI, 4), resting against tilted Lower Karewa beds. As it is 85 feet high it is a prominent landmark. Its surface is covered with faceted erratics, some of them measuring 900 cubic feet. The photograph (pl. XXI, 4) shows it from the upstream side, with the river cutting through it. On the right bank lateral moraines with striated pebbles almost merge into the ridge.

Two furlongs downstream another terminal moraine, which is equally thick, is found at about 6,100 feet, and 1,000 feet farther down, above the second stream junction, a third one is encountered at 5,920 feet. This third moraine is broken up into two small walls, 600 feet apart, but connected by a clayey boulder deposit. This marks the terminal of the third glacier at its maximum length. The Karewa clay beds on the slope are crumpled along the contact of the moraine, apparently owing to pressure of the glacier snout during its farthest advance. Beyond this lowest moraine the valley is choked with boulder gravel representing the accumulated outwash from glacial débris. Terraces were not observed, but it is very probable that originally the glaciofluvial gravels filled most of the valley and that from them was derived the gravel of the lower fan across which the Mudri discharges into the Jhelum River.

South of Dangarpur several rivulets descend from the higher mountain slope and join the main river below the last moraine. At the outlet of the largest one a lateral moraine was seen at an altitude of 6,300 feet. From here on boulders cover the lower slopes. Here, tonguelike ridges, composed entirely of coarse angular débris, emerge from the forest. In view of the absence of striated rocks this deposit may represent solifluxion débris of the third glacial stage.

In comparison with the moraines found in the lower Ningle Valley, it appears that the same number of retreat stages are represented here, and that the two glaciers advanced to the same low altitude (6,000 feet). In no other region of the Pir Panjal in Kashmir did the third glaciation reach so far down into the valley basin. A look at the map shows that the mountain slope is here so unusually steep that the river of Dangarpur falls 2,000 feet over a course of 1½ miles. Un-

questionably a similar steep gradient promoted the downward advance of the third glacier, thereby depositing moraines at an abnormally low altitude. As the lowest moraine lies some 4 miles from the Jhelum Valley and 850 feet above the master stream, it follows that the Jhelum Valley in this region was not glaciated either during the third or the fourth ice advance.

To test this conclusion it was necessary to study the position of glacial formations and terraces in the adjoining Jhelum tract.

E. GLACIATION OF THE SOUTHWESTERN SLOPE AND ITS CORRESPONDING FEATURES IN THE FOOTHILLS OF JAMMU AND POONCH

GLACIATION OF THE JHELUM TRACT

Glacial Deposits and Terraces in the Upper Jhelum Valley between Naushera and Rampur

The Jhelum River 10 miles below Baramula is just close enough to the upper Ningle drainage basin to permit geologic correlations. One of the left tributaries actually drains the watershed between the Gulmarg region and the Jhelum, and it is in this side valley, called Gratnal Nullah, that consecutive observations were made for the sake of establishing contact with the upper Jhelum tract (fig. 103). Situated so near to the feeding ground of Pleistocene glaciers, this area appears to be most favorably suited for an investigation of glacial history in one of the major Himalayan transverse valleys.

The Jhelum glaciation.—From the foregoing discussions of the Pir Panjal glaciations, particularly those recorded in the Gulmarg and Tosh Maidan regions, it would follow that nowhere did the third and fourth glaciers reach much below 6,000 feet on the Kashmir side. As the Jhelum bed, downstream from Baramula, lies more than 1,000 feet below that level, the absence of any glacial records belonging to these stages might well be expected. Moreover, we have shown that the first glaciation was very weak and restricted to the now highly elevated slopes of the watershed range, which makes it most improbable that the Jhelum Valley at that early stage ever carried glaciers. On the other hand, we have demonstrated that the second glaciation was the most effective in this range, and, if our general deductions are correct, we would expect to find its records as prominently displayed along the Jhelum as in the other valleys.

The traverse of the Ningle-Jhelum watershed, on the path leading from Gulmarg to Naushera, offered a good opportunity to follow the extent of the boulder moraines previously assigned to the second glaciation. The undulating and softly rounded slopes of Washtu Peak (11,027 feet) are made of brown bouldery loam, which rests against the steep higher flanks of this mountain. Viewed in profile this loam seems to fill a very wide trough at Sawanwali. The headwaters of the Mudri River, a tributary of the Jhelum, have dissected this ancient fill to a depth of over 400 feet without exposing bedrock. On top of the brown loam one occasionally encounters ridges of morainic débris (at 9,500 feet), which follow the valley slopes. They appear to originate in cirquelike depressions on the higher

slopes above 10,000 feet. To judge from their fresh appearance, these moraines might belong to the third advance, especially as they can be followed downstream to an altitude of 7,400 feet, where they make a distinct lateral moraine below the hamlet Thelan (fig. 103).

The upper Gratnal Valley above Thelan is comparatively wide, with bouldery clay moraine filling the floor as much as 300 feet thick. Below this settlement

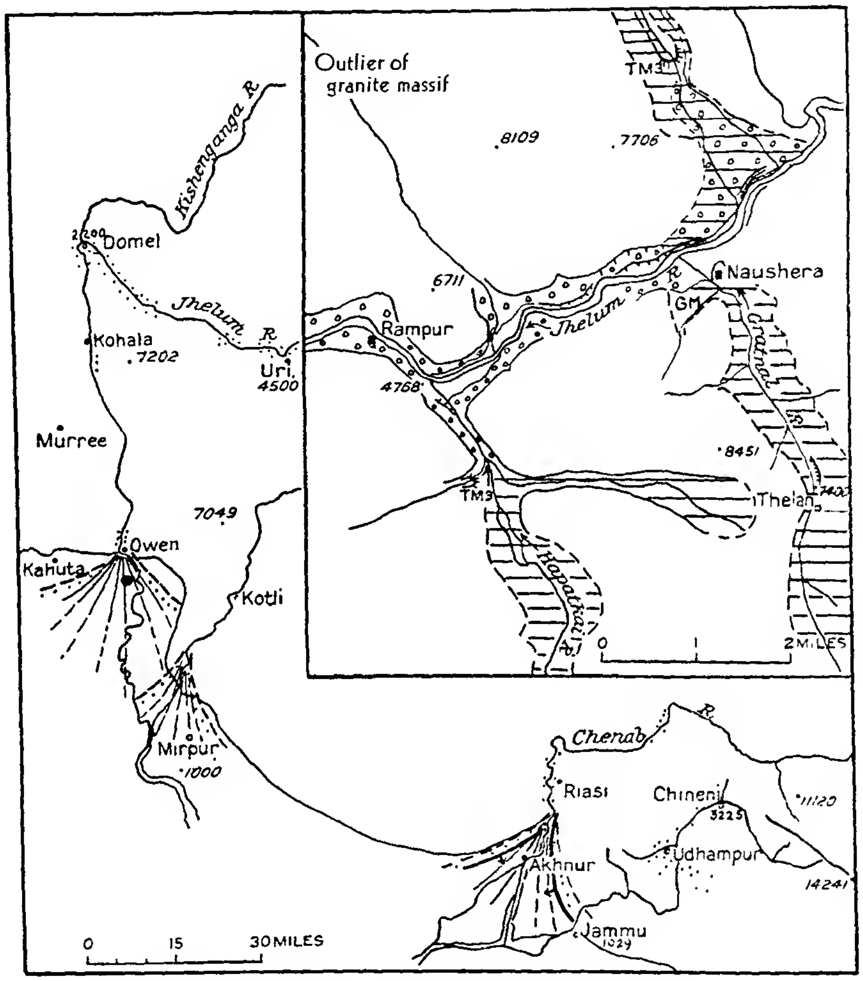


FIGURE 103.—Map of glacial deposits in upper Jhelum Valley (inset) and in neighboring valleys of southwestern Pir Panjal. Stippling indicates glacial boulder débris.

the gradient is extremely steep, the river descending 2,500 feet within 2½ miles to its confluence with the Jhelum. This extraordinary steepness is doubtless due to overdeepening of the Jhelum tract, which accelerated perceptibly after the boulder moraine filling had come into existence. As one descends, the moraine consequently is found at ever-increasing heights above the stream bed. Spurs of intertributary divides are clearly truncated wherever the thick boulder formation rests against them. Along the path on the right slope large erratics were encountered some 200 feet above the river.

At the valley outlet near Naushera the stream breaks through a thick fanlike formation (pl. XXII, 1) before joining the Jhelum. This deposit is over 400 feet thick, and 260 feet of it is exposed on a steep bluff facing the river. Its upper part is composed of faintly stratified boulder gravel and sand with clay lenses; its lower part consists of erratics and débris lying in disorderly fashion in a matrix of brown sandy clay. To judge from the weathered condition of trap boulders and from the faceted shape of the detritus, this lower formation must belong to the boulder moraine found in the upper valley tract. The upper part is equally weathered, and as the débris is more worn and slightly stratified, it can only represent a glaciofluvial fan lying on top of ground moraine. This must mean that the Gratnal Glacier flowed into the Jhelum Valley, where it must have merged into other tributary ice streams. Indeed, the same composite fan is found on the right

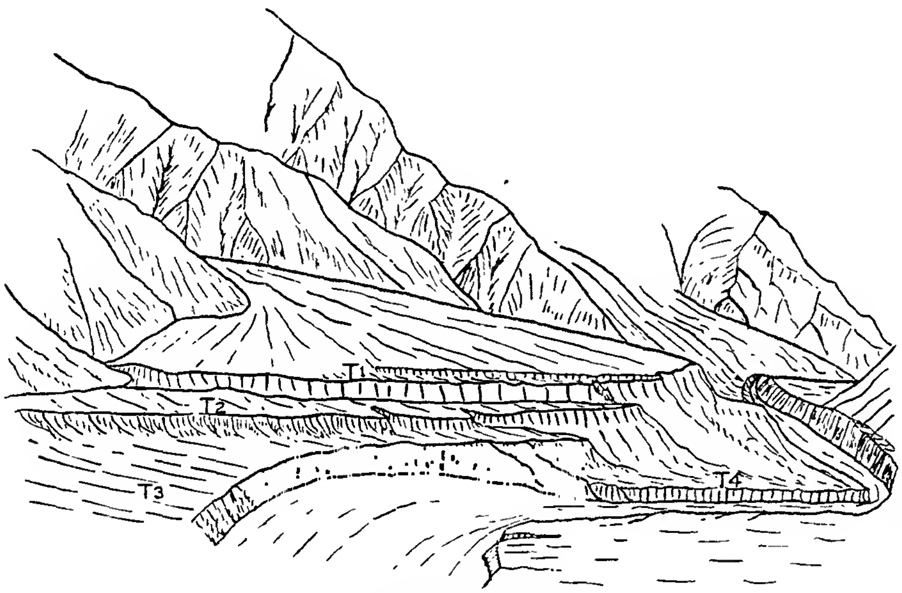


FIGURE 104.—Terraced fan of second glacial age opposite Naushera. T1, etc., terraces.

bank of the Jhelum above Naushera (pl. XXII, 2). Its preservation is so perfect, as figure 104 illustrates, that it deserves special mention above the other fans that occupy the valley outlets all along this tract. Next to the terraces, these fans are the most conspicuous features in the Jhelum Valley, marking a period of colossal aggradation. The composite fan is 2 miles wide at its base and about 1½ miles long, and rises gradually, 200 to 1,000 feet above the river. Its lower end is deeply trenched by two streams and cut off by a precipitous cliff or at other places by terraces.

Boulder gravel accompanies the river on both sides (fig. 103). It forms a narrow fringe of detritus, and on its silt-covered surface the Kashmiris have built their houses and cultivated maize and rice. In the next side valley, above Rampur, this formation is seen to make a high terrace, 160 feet above the river, which continues upstream for some miles. Here brown loamy clay replaces the

sandy matrix, and erratics appear once more on the higher slopes. The valley is slightly U-shaped, and the spurs are truncated. From it issues, as Oestreich (1906, p. 95) observed, a boulder moraine. Although the trough floor in this side valley lies at about 6,000 feet, the upper visible limits of glaciation are at 8,000 feet. The trough shoulder is very distinctly marked by narrow rock benches on inter-tributary divides which form a uniform ancient floor over which the glacier moved into the Jhelum tract. To judge from the distribution of boulder moraine it would seem that this trough valley was shaped by the second glacier. Several hanging valleys above the trough shoulder were observed near Bachi, their outlets being 2,000 feet above the present river level.

As the boulder gravel is followed to Rampur the amount of porphyritic granite is found to increase perceptibly. Here large erratics of this rock have weathered out from the terrace, some of them measuring over 900 cubic feet. The deposit is some 160 feet thick and composed of subangular boulders lying in a matrix of gravelly sand with brown silt interbedded. This structure and the apparent foreign derivation of the granite erratics induced Lydekker (1878, pp. 30 ff.) and later Dainelli (1922, p. 587) to regard the Rampur boulder gravel as a fluviatile drift, corresponding to a very large ice advance on the Himalayan slope of the Kashmir Basin. According to Dainelli, the erratics were floated by ice that broke off at the snout of a Sind Valley glacier, drifted across the Karewa Lake, passed the spillway at Baramula, and finally were dropped 15 miles downstream. This ingenious interpretation is in our view correct, so far as it recognizes the relation of the boulder drift to a major glaciation. Apart from this it lacks the possibility of explaining satisfactorily the erratic blocks. It is, for instance, unthinkable that a river could transport in floating fashion, in an easy journey through a narrow defile, ice débris of such gigantic size. Even if, as was speculated, the ice cakes were dislodged and carried downward by a catastrophic spilling of the Karewa Lake, it is difficult to understand why they should have accumulated at Rampur and not 5 miles farther on, where the Jhelum Gorge begins. And yet, there are here no traces of erratics, which should have accumulated heavily at the first narrowing of the stream passage. In any case erratics are not restricted to this tract. They occur locally at the surface of terraces or fans near Uri, where they consist of granite and various metamorphic rocks. Moreover, Wadia (1934, map) has mapped a biotite-granite massif on the right valley flank some 4 miles north of Rampur, which is exposed by the headwaters of various tributaries. The easternmost of these streams was especially effective in denuding the granite, and as the second glaciation was recorded in this valley (fig. 103), it is more plausible to conclude that a glacier carried its débris into the Jhelum tract and that the erratics were subsequently dropped in the ground moraine of the main valley. This conclusion not only spares us the necessity of explaining their distant origins but it accounts for the existence of a Jhelum glaciation in this neighborhood.

There remains, however, the question of how the erratics came to be deposited in the fluviatile boulder gravel. As explained above, the fans are composed of both moraine and overlying outwash débris. In the valley proper only the out-

wash is encountered, but obviously ground moraine at one time filled the glaciated tract. During the glacial retreat the moraine was denuded, and its coarsest débris was incorporated in the succeeding outwash gravel.

This conception of the Rampur boulders confirms Oestreich's explanation (1906, pp. 94 ff.) with its convincing interpretation of the tributary glaciation near Rampur. Oestreich denied, however, as did Dainelli, the existence of an individual Jhelum Glacier, because he observed, near Uri, how the moraine at the outlet of a side valley gradually merges into glaciofluvial outwash. With this conception, however, it is difficult to see how the granite erratics got to Rampur, which lies 2 miles from the outlet of the valley through which the side glacier descended. In addition, the boulder moraines below the fans are so thick that one is obliged to assume rather powerful glaciers at the junction of main and side valleys. These should have led to at least local glaciation of the Jhelum tract.

How far this glaciation extended downstream is difficult to say, as no continuous mapping was carried out. Oestreich has described in detail the moraines at Uri, 10 miles below Rampur, where they lie at an altitude of 4,500 feet. From Uri to Kohala, over a distance of 68 miles (fig. 103), the coarse boulder gravel can be followed all along the stream, and there is every reason to believe, as Oestreich stated, that these deposits represent in part outwash from the moraines of various tributary glaciers lodged on the southern slope of the Pir Panjal. Their association with the moraines of the second glaciation being established, it would seem that these coarse boulder gravels of the lower valley are intimately linked with the largest of the Pir Panjal ice advances. However, there are no erratics and no true moraines known in this lower tract. Hence we can say that the Jhelum Glacier was restricted to a short valley section between Naushera and Uri. Its length presumably did not exceed 15 miles.

Nevertheless it is difficult to reconcile this local glaciation with previous observations that point to an ice-free spillway at Baramula during the major ice advances. Then it was shown that these advances did not affect the Kashmir Lake Basin, and yet 10 miles below its spillway, we have traces of glaciation. Obviously the main valley formed a glacier only in its upper tract, where it broke through the highest part of the range. From this tract the ice flowed off, and as it descended the important tributaries it reached the main valley. Here the side glaciers coalesced, thereby forming a local ice stream in the main valley.

Downstream from Uri boulder gravel and fan deposits take the place of moraines and other glacial material. These deposits generally issue from side valleys, where they eventually merge, upstream, into terminal or lateral moraines of the second glaciers. According to the degree with which the valley descends the Pir Panjal slope, glaciofluvial gravels become replaced more and more by ill-assorted detritus and boulder gravel. Such deposits are easily recognized by the brown-pinkish color which the purple-red Murree formation lends to the Pleistocene valley fill. Another characteristic is their great thickness, which appears to increase toward the Jhelum outlet to the plains. But beyond Kohala the river has effectively removed most of the older fan material. Here the Jhelum flows in a

deeply incised valley in which only local remnants of terraces and fans are visible, many hundreds of feet above the stream. At some places, such as above Domel, the fan deposits assume a pseudomorainic composition. These are landslide deposits of such coarseness as is unknown in recent débris of analogous origin. Whereas the present river constantly undercuts the slope wash without giving it a chance to accumulate to greater thickness, the older river apparently was unable to cope with the heavy deposition. This process must have coincided with a time of excessive filling and of diminished stream power. Such conditions could have prevailed only at a stage when a great portion of the run-off was locked up in the form of ice. At this time nivation and solifluxion were unquestionably more effective than in recent time, and with periglacial conditions superimposed on this youthful slope relief it is easy to see how such factors dominated denudation at the expense of stream action. This should have led to a rapid grading of the master stream, which heightened its channels progressively from the valley mouth upstream toward the glaciated tract. Hence the aggradation was the result of both upward grading (beginning at the outlet to the plains) and contemporary filling by landslides. In this way the valley fill would have acquired a heterogeneous composition, with coarse talus and river gravels alternating, not forming a "cyclic" structure with coarse material at the bottom and finer sediment on top. Indeed, the older Jhelum detritus shows precisely this continuity of coarse deposition and, what is more, the great "Boulder conglomerate" fans of Upper Siwalik age at the valley outlets, northwest of Kahuta, are similarly composed. The only difference is that in this fan all the components are water-worn. The "Boulder conglomerate" here lies some 40 miles downstream from Kohala. Its composition of hard metamorphic and Paleozoic rocks, traceable to the boulder gravels and fans upstream, leaves no doubt that the topmost Siwalik beds merge into the boulder gravels and fans of the middle Jhelum tract.

The regional expansion of a fan or fill stage from the Himalayan slope to the foothills of the lower Jhelum tract and its association with glaciofluvial outwash and moraines of the second glaciers are established. It remains now to be seen whether the Jhelum terraces correspond to the river levels previously described from the Kashmir region.

Terraces of the Jhelum Valley.—Earlier travelers, especially Drew and Lydekker, later Oestreich and Dainelli, have commented on the terraces that form conspicuous features of the Jhelum Valley. Indeed, without these terraces the valley would be a forlorn sight. Their green cultivated fields contrast with the bleak, rocky slopes and lend to the scenery a definite air of human planning. On them villages and smaller towns are nestled against the talus-strewn valley flanks, protected, as it were, from the ravaging spring and summer floods. Temple ruins testify to the great antiquity of some of these settlements, which date back to the first millennium of our era.

Previous observers, like Godwin-Austen (1864, pp. 383 ff.) and Lydekker (1878, pp. 30 ff.), thought that these terraces are of fluvial or glaciofluvial origin. Oestreich (1906, p. 95) remarked that the 40-meter terrace near Rampur, at Banihar temple,

and the lower river levels "mögen eingelagerte Moränen oder fluvioglaziale Bildungen sein, den einzelnen Gletschervorstössen oder Interglazial Zeiten entsprechend." He recognized three terraces which are developed below the large fans. At Banihar they lie 60, 40, and 5 to 8 meters respectively above the stream. No attempt was made to date their origin. Dainelli (1922, pp. 582 ff.) called attention to two major terraces between Baramula and Uri and to three levels above Kohala and near Domel, which surmount the river by 70 to 80, 45, and 25 meters. Assuming that the valley witnessed one large fill stage (between the first and third interglacial periods) to which Dainelli attributed the large fans, he concluded that their origin might be due both to uplift during the third interglacial period and to later glaciations.

Obviously an analysis of these features can be attempted only in the formerly glaciated tract—namely, between Rampur and Naushera. The large fan opposite Naushera may serve as the type locality, not only on account of the complete

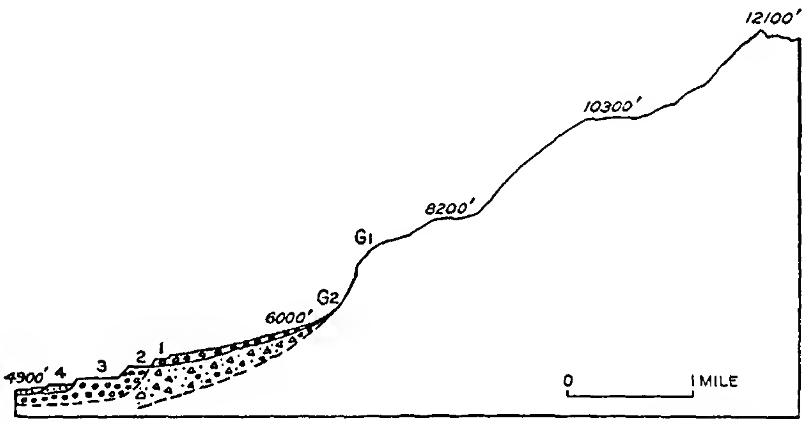


FIGURE 105.—Composite slope profile of right flank of Jhelum Valley above Naushera. 1, 2, 3, 4, terraces; G1, G2, ancient valley flows.

terrace sequence, but because of the presence of two moraines in its vicinity (figs. 103 and 104). From the right bank four levels can be recognized. The topmost lies at the streamward edge of the fan and is ill preserved in the form of a narrow ledge, some 300 feet above the stream. The second is much wider, 40 feet below the first, and is built of different material. Its gray gravel is water-worn and homogeneous in composition, and its level corresponds roughly to that which bevels the edge of the second moraine at Naushera. In comparison with the fan it has no true moraine character, and although bouldery it would seem to belong to a later fill stage at which the valley was no longer glaciated. Inasmuch as the neighboring tributary, as well as the Gratnal and Hapatkai valleys, show terminal moraines of the third glaciers lying intermediate between the large fans and a lower wide terrace (T3), it follows that this second terrace gravel must be glaciofluvial outwash from those glaciers. A prominent slope of over 100 feet separates T2 from the third level (T3). This is the widest terrace, which can be followed downstream to Uri, where its level (4,400 feet) is cut into the morainic gravel of the third

glacier. Presumably this is Oestreich's 60-meter terrace. The degradational origin of T3 is also evident from a corresponding rock bench opposite the fan above Naushera. Here the fourth terrace gravel is less coarse than that of T2 and T3. It is a boulder-bearing loosely packed river gravel of recent appearance which seems to be banked against the slope below T3. This marks the second aggradation of post-fan age, unquestionably analogous to that of the fourth ice advance in the other Pir Panjal valleys. A lowest bench finally occurs locally at Rampur and Uri, representing a fifth level which lies 15 to 20 feet above the river. This marks the youngest aggradational stage (fig. 105).

Comparison of the sedimentary composition of these Jhelum terraces discloses the following arrangement:

	Thickness in feet
Fans: Ground moraine overlain by very coarse little-worn talus and glaciofluvial outwash. Boulders with brown patina, erratics of granite, and Paleozoic rocks of great variety	±400
Gravel of T3 and T4: Coarse bouldery river gravel, ill assorted but stratified with intercalated sand. Gray color. Components mainly Paleozoic slate and trap and Murree sandstone in lower tract. Very little granite near Rampur	±120
Gravel of T4: Bouldery, well-assorted gravel and sand. Components waterworn, mainly quartz, quartzite, slate, and Murree sandstone exclusively in lower tract	100–120
Gravel of T5: Coarse gravel with occasional boulders	±15–20

This composition reflects the glacial and orogenic events characteristic for the Pleistocene in Kashmir. The early Quaternary and preglacial history in the Jhelum tract, up to the second ice advance, left no sedimentary records except for the lower Karewa fans near Baramula. But previously attention was drawn to the presence of at least two levels developed on higher spurs (fig. 105). The lower one lies some 3,300 feet and the other 5,400 feet above the stream bed. The former corresponds to a ledge developed on interstream divides, some 1,100 feet above the trough shoulder of the second glacier in the Hapatkai Valley (fig. 103). This, we believe, is part of the elevated mature relief of the Pir Panjal, which became dissected before the second glaciation set in. Its origin may be of early Pleistocene or somewhat older date. The largest glaciation, recorded by fans and moraines, was followed by another dissection due to uplift. To judge from the erosional effect it had on the fans, this uplift was weaker than the first interglacial movement. A third uplift caused dissection of the third glacial fill, and after the Jhelum had graded its course, another rejuvenation set in, which formed the slope above the fourth terrace. This development is in harmony with our interpretation of the Kashmir terraces. Its regional applicability, therefore, is established so far as southwestern Kashmir is concerned.

Even beyond the political realm of Kashmir—namely, downstream at Domel, in the Punjab—the same terrace arrangement appears. Here the confluence of the Kishenganga and Jhelum rivers (fig. 103) led to the formation of a wide tri-

angular basin, filled with gravels and bouldery detritus. Four terraces (T2 to T5) can be seen, and these repeat principally the arrangement of the terraced fans near Naushera.

Unfortunately, the Jhelum has, through recent erosion, destroyed most of the records below this place, so that it is not possible to follow the Jhelum terraces into the plains. If these can be found in a similar arrangement at the outlet of one of the neighboring big transverse valleys, such as the Chenab, it is obvious that the terraces of Kashmir and the underlying fan formations can provide a better understanding of Pleistocene history in the foothills and plains.

OUTLET OF THE CHENAB VALLEY AT AKHNUR

More powerful still than the Jhelum, the Chenab River breaks through the eastern Pir Panjal in the form of a gorgelike valley whose precipitous flanks rise 6,000 to 8,000 feet above the stream. Such dissection does not allow for preservation of gravel terraces or fans, and the middle part of the Chenab Valley, therefore, lacks the geologic records which make the Jhelum tract so attractive. Here and there terrace remnants are perched 400 or 600 feet above the roaring stream. Higher on the slopes rock ledges and beveled spurs testify to ancient valley floors, the origin and age of which cannot even be guessed at. It is equally unknown whether the main valley ever was glaciated as low down as Ramban (2,138 feet), but from Norin's studies (1926) it would appear that the upper tract above Kishtwar was, at one time, subjected to heavy glaciation. In fact, in the headwaters of the tributary that joins the Chenab above Kishtwar, glaciers of the main Himalayan range still reach down to 12,000 feet. The close vicinity to the high Himalaya makes it almost certain that the Chenab tract was glaciated down to at least 4,000 feet, or approximately 110 miles from the outlet above Akhnur.

Over this distance the gorgelike valley contains remnants of an old valley fill. It is a very coarse boulder conglomerate of reddish color in which angular and slightly water-worn blocks lie in a gravelly and silty matrix. Rapid changes of facies, due mainly to interbedding with coarse talus débris, characterize this formation as a torrential valley fill of great thickness. Its components are derived essentially from three formational groups—(1) Paleozoic, igneous, and metamorphic rocks, (2) Murree sandstone (Miocene), and (3) less abundant Siwalik rocks. The Siwalik rocks appear only in the lower tract, where the stream cuts through the early and middle members of that series, and even here their share is insignificant in comparison with the former rock supply. It is to be expected that Murree sandstone and soft Paleozoic slates were progressively eliminated in this formation as the river continued its downward course, and hence one can anticipate finding the old valley fill at the outlet composed mainly of the harder rock material derived from the Paleozoic and crystalline core of the higher ranges.

Some 16 miles above Akhnur, in the vicinity of Dera, the Chenab meanders in a deep valley across the western slope of a ridge that strikes due south toward Jammu (fig. 106). This ridge I have described (De Terra and Teilhard, 1936, pp. 802 ff., fig. 7) as a huge boulder fan, tilted toward the plains, which overlies fossiliferous,

older Upper Siwalik beds of early Pleistocene age. These beds contain *Stegodon ganesha*, *Bos*, *Equus*, *Elephas planifrons*, and *Hexaprotodon* cf. *sivalensis*. It is the "Boulder conglomerate" of Pilgrim and other investigators, which forms a monoclinal ridge here, gradually ascending northward until, near Dera, its crest lies 1,200 feet above the Chenab River. The components of this formation are hard rocks, mainly quartz, quartzite, and metamorphics, much water-worn but all the size of a mature human head and even larger. On the opposite river bank a similar ridge appears with northeast-southwest strike, equally tilted and of similar composition. From the junction of both ridges at the very point where the river emerges from older Siwalik beds, it becomes evident that they belong to one

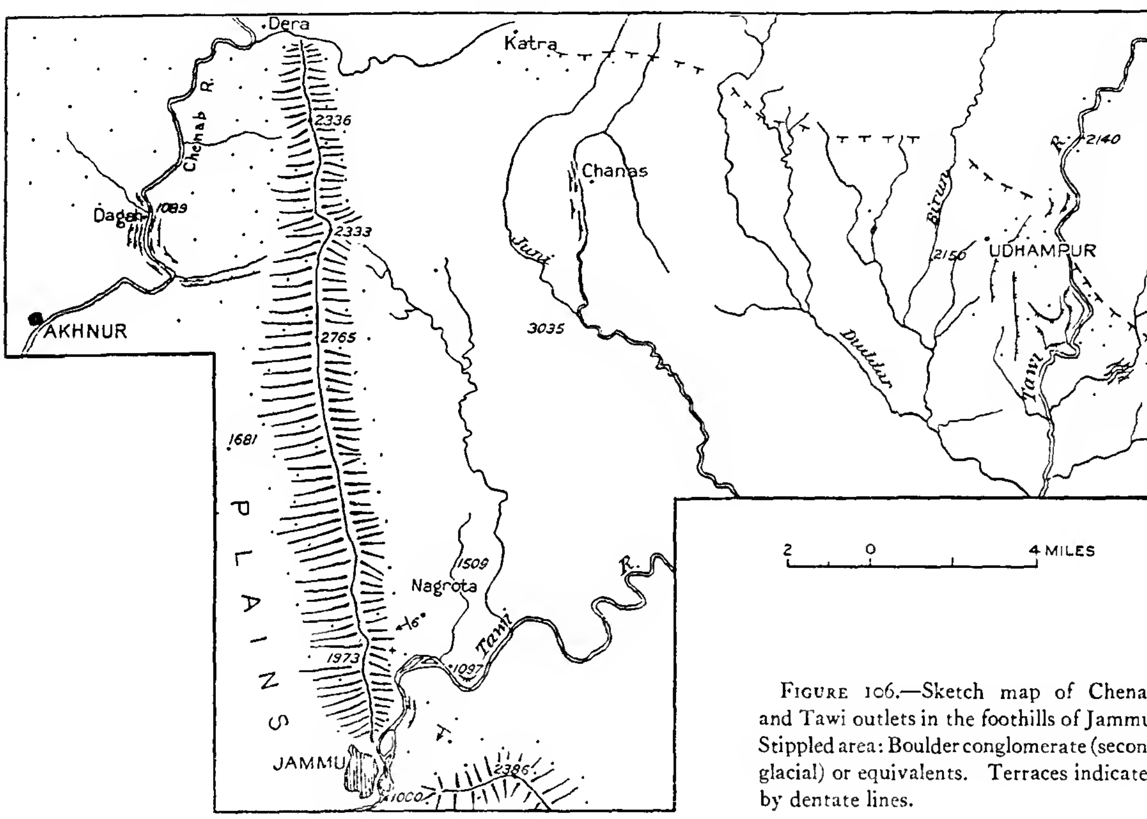


FIGURE 106.—Sketch map of Chenab and Tawi outlets in the foothills of Jammu. Stippled area: Boulder conglomerate (second glacial) or equivalents. Terraces indicated by dentate lines.

large boulder fan which issues at an old valley outlet (fig. 103). The fan was uplifted with older Siwalik formations in such a manner as to form two cuestas, which diverge from the apex near the valley outlet, and the Chenab, superimposing its course upon the center of the fan, followed the medial depression. In other words, the master stream is antecedent to the uplift, its present meanders being somewhat shifted in the fan according to the alternating supply of slope wash from young tributary slope streams.

The nature of this fan and its merging into the older valley fill upstream make it fairly certain that both belong to one and the same aggradational stage. In view of its superposition on early Pleistocene beds, belonging to the Tatrot-Pinjor stages of Upper Siwalik time, we must conclude that it is somewhat younger.

As demonstrated below, a terrace system analogous to the Kashmir pattern is developed along the Chenab, indicating a prolonged period of stream erosion. Hence the Boulder conglomerate was formed at a time intermediate between the early Pleistocene and the later terrace formation. This is precisely the same position which the boulder fans and Karewa gravels hold within the Pleistocene sequence of Kashmir. These deposits have previously been explained by glacial accumulation and outwash during the greatest ice advance in the Pir Panjal, and one cannot help but apply the same interpretation to the boulder fan of the Chenab. At no other period was the supply of rock material as great as in this phase, when the valleys were laden with morainic and slope débris. Once the ice retreated, this vast supply was set free to be transported toward the plains. Uplift in the center of the range may have quickened this process, so that an abnormally large amount of débris was dumped at the valley outlet. In fact, the great thickness of the fan, amounting to over 1,800 feet, can be satisfactorily understood only if it is assumed that the floor of the fan sank as the foothills rose.

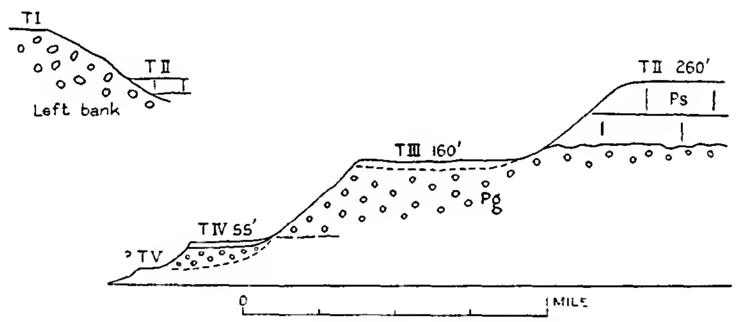


FIGURE 107.—Chenab terraces (TI, TII, etc.) above Akhnur, opposite Dagah. Pg, Potwar gravel; Ps, Potwar silt.

Just as in Kashmir fan formation followed the early Pleistocene (first glacial and interglacial stages), so did the Boulder conglomerate succeed the early Quaternary Siwaliks. Consequently, the fan formation is of middle Pleistocene age and to be broadly correlated with the second or major Pir Panjal glaciation. A direct proof of this conception, finally, is the presence of glacially faceted boulders in the ridge above Jammu (De Terra and Teilhard, 1936, p. 802). The stray occurrence of rolled quartzite flakes of pre-Soan type in the upper layers indicates the presence of early man during a late outwash phase of this period. (See part II of this memoir.)

The Chenab terraces above Akhnur.—About 3 miles upstream from Akhnur the Chenab makes its last great meander before braiding its bed into numerous channels. Here also it undercuts, for the last time, the slope of the boulder ridge. This slope is dissected by a great number of young tributaries, which could have originated only after uplift of the fan. Since then the slope streams have cut various terraces, some of which are also found in the Chenab Valley proper. Just below the dip slope of the fan, which is perfectly even except for a few cuestalike scarps, another level can be seen (fig. 107 and pl. XXIII, 1, T1). It appears to have been cut into the tilted surface of the fan. A second level (T2) is

prominently displayed on the uninvestigated left bank. However, on the opposite side appears a plateaulike surface at a similar altitude. This is underlain by yellow loessic silt somewhat similar to the Upper Karewa beds of Kashmir but distinguishable from them by its composition and structure, as in the lower beds it contains sand and gravel, and in general it is less distinctly stratified. To anyone familiar with the geology of the Potwar region, near Rawalpindi, in the northwest Punjab, it is easy to recognize in this formation the "Potwar loessic silt," which has previously been described by Wadia (1928) and me (De Terra and Teilhard, 1936). Near Dagah its upper surface lies 260 feet above the stream, but farther west it rises and is broken up into hillocks. The thickness of the silt in this section is about 80 feet. Below the silt is a coarse gravel into which a lower terrace (T3) is cut. This gravel clearly antedates the two terraces and, to judge from the exposures on the opposite bank, it seems to make a deep valley fill, which the Chenab finally degraded to form a wide terrace (T3). From this relation we infer that the river trenched the first terrace, whereupon it aggraded its valley, first depositing coarse bouldery gravel, and then silt. The silt, being partly of fluvial and partly of eolian origin (De Terra and Teilhard, 1936, pp. 814 ff.), marks the depositional level T2. This silt fan, as it may be called, was in turn deeply dissected, until the river began to meander again, stopping at a level which now lies 160 feet above the Chenab (fig. 107). The highest terrace slope occurs below T3. At places it is 140 feet high and exposes the same boulder gravel in this thickness. The succeeding terrace (T4) lies about 55 feet above the stream and is underlain by a second coarse gravel in which boulders are more scarce. This terrace has a thick veneer of loam. Into this the Chenab has cut its present bed. However, as observations were restricted to a small area, it is possible that a fifth terrace is present somewhere below or above the section under discussion.

From these observations it would appear that the Chenab outlet recorded principally the same stages as were found in the Jhelum and other valleys in Kashmir. We can distinguish two major phases of fan formation, represented by the Boulder conglomerate fan (second glaciation) and a younger, smaller fan composed of boulder gravel and silt. The younger fan unquestionably is homotaxial with the outwash gravel of the third glaciation. (See Paterson's section on Poonch Valley.) Now, the correlation of the loessic silt with the Potwar silt is of importance in regard to the origin of this formation. As this problem is discussed in greater detail at another place, it is here only necessary to mention the occurrence of Levallois flakes as horizon markers in the loessic silt of the second terrace. Such flakes were abundantly found either in the basal gravel of the Potwar zone of the northwest Punjab or in the lower silts. Above Akhnur half a dozen flakes were collected from the lower silt. This appears to corroborate our correlation with the silt of the Potwar area.

TERRACES AND FAN DEPOSITS IN THE TAWI VALLEY ABOVE JAMMU

Upper Tawi tract.—The Tawi is a tributary of the Chenab, descending from the crest of the sub-Himalaya east of Udhampur (fig. 106). Its source lies close

to 12,000 feet in the vicinity of a high peak (14,241 feet), the altitude of which rivals that of the Pir Panjal. Like the Chenab, in its upper course it follows the orographic and geologic strike of the range, but its middle course cuts through the fore range as the river meanders through steeply folded Siwalik beds. At the great bend where the transverse valley begins lies the small town of Chineni (3,225 feet) (see fig. 103). It was here that Medlicott (1876, p. 53) recognized Siwalik conglomerates lying unconformably on older slate rock and Murree sandstone. From his cursory description it is not clear whether these Siwalik beds are the same as those which appear downstream at Udhampur, but as he mentioned red clays and boulder beds from Chineni, it must be assumed that he meant the old valley fill that makes a prominent terrace at the river bend. This formation clearly resembles both the boulder gravels of the middle Chenab tract and the Boulder conglomerate as developed near Jammu. It is less well stratified, and the boulders are subangular throughout, lying in a red matrix of silt and sand. On the terrace slope which exposes a thickness of several hundred feet large blocks have weathered out. Some of these measure 400 cubic feet and more and show smoothed facets as if they had been derived from glacial action. This character and the composite nature of the terrace deposit suggest an origin similar to that of the Jhelum boulder gravels below Uri. In other words, it is rewashed and partly residual ground moraine mixed with landslide material. The presence of erratics at such low altitudes (about 3,500 feet) can be explained only by a glaciation of the longitudinal valley section above Chineni. From here the steep river gradient leads over a distance of some 15 miles to contour 6,000 feet, into the slope of the Chenab-Tawi watershed. Its altitude is such as to warrant the assumption of a Pleistocene glaciation. In analogy to the Jhelum Valley it is evident that only during the second glaciation could the glacier have been able to advance down to about 4,000 feet. This would have brought the ice to about the same altitude as in the Jhelum tract, and it would have furnished morainic débris for the entire lower valley as far as Udhampur and beyond.

Downstream the Tawi Valley displays at least two terraces, which are underlain by the same red boulder formation. Its thickness increases notably at the valley entrance into the basin of Udhampur. This entrance coincides with a border fault through which older Upper Siwalik beds are dropped against older formations (fig. 106). The boulder gravel now assumes fan structure and spreads throughout the basin. Murree rocks, little worn and of varying size, are its most prevalent components. No doubt this sudden increase of Murree sandstone débris at the fault line is the direct outcome of the great displacement which befell the Upper Siwalik beds. Through it the older Siwaliks and especially the Murree formation were subjected to violent denudation. If our contention is correct that this boulder fan is homotaxial with the older valley fill at Chineni, it can, by analogy with the Chenab and Kashmir valleys, be expected, first, to rest unconformably on early Pleistocene beds, and second, to have undergone terracing similar to that at the Chenab outlet.

Previously (De Terra and Teilhard, 1936, pp. 805ff.) I have shown that the basin filling at Udhampur contains strata that bear all the characteristics of the Tatrot-

Pinjor zones near Jammu. Also the bluish-gray laminated clays found near Dhalpar (above gray conglomeratic sandstone) have the appearance of the Lower Karewa beds in Kashmir. Fresh-water shells found in them are identical with species occurring in the Karewa lake beds. In addition the tilting of these beds shows the same degree of deformation which characterizes the lower Pleistocene on the Kashmir flank of the Pir Panjal. There is, then, little doubt of their representing the early Pleistocene. North of the aforementioned place a high leveled spur,

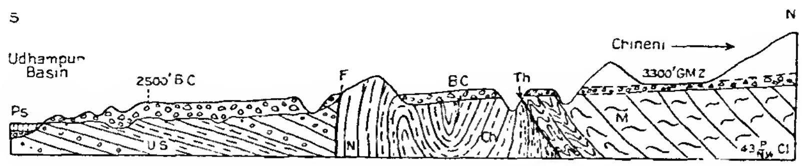


FIGURE 108.—Longitudinal valley section along Tawi River above Udhampur. U.S., Upper Siwalik (Tatrot-Pinjor beds); Ch, N, Lower and Middle Siwalik; M, Murree sandstone; B.C., Boulder conglomerate (second glacial); GM2, ground moraine; Ps, loess (third glacial); F, fault; Th, thrust fault.

some 300 feet above the basin floor, projects from the fault scarp (pl. XXIII, 2). This spur is made of red Boulder conglomerate some 420 feet thick, which lies unconformably on tilted Upper Siwalik beds. It represents a dissected portion of the great Tawi fan lying, as it were, against the fault scarp (fig. 108). This situation fulfills one of the requirements for our stratigraphic correlation with the Chenab and Kashmir regions.

The other condition concerns the terrace formation. In this respect the Udhampur Basin furnishes equally convincing evidence. Not only at Udhampur

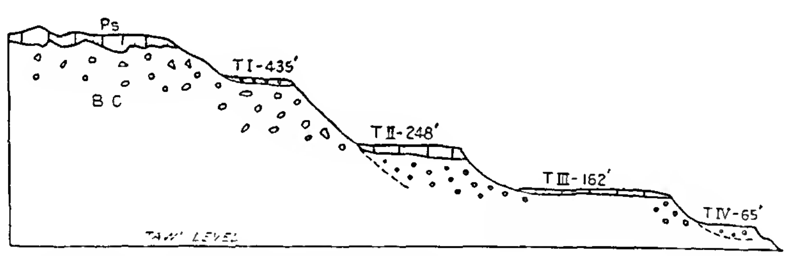


FIGURE 109.—Terrace sequence in Udhampur Basin. Ps, Potwar silt; B.C., Boulder conglomerate.

itself but in all tributary valleys, as far east as Ramnagar, terraces or remnants of them abound (pl. XXIII, 3). The most complete section that came under observation lies east of Udhampur, on the right bank of the Tawi (fig. 109). Here the river flows around the eastern rim of the great boulder fan that issues from the upper Tawi Valley. This fan is exposed on the slope above T2 and again below this terrace. It is a purplish-red conglomerate, stained by Murree rocks, with a sandy-gravel matrix and thin red silt interbedded. Above it lies a pink silt with basal gravel. This veneers the slight relief of the fan, filling its depressions with pockets of sandy gravel. At many places the topmost conglomerate layer is

greatly leached and its sandstone components disintegrated. All this points to a period of erosion and weathering prior to the deposition of the red silt. This silt is about 40 feet thick and shows faint banding. Like loess, it makes for vertical walls, and its composition is monotonous except for slight color variations. It can readily be compared with the loessic silt in the Chenab outlet, its only difference being the red color, which is due to local supply with Murree and Lower Siwalik silt. Loessic silt builds the upper surface of the fan on which stands the ancient city of Udhampur. An old terrace (T1), which is cut into the upper edge of the fan, appears to lie submerged underneath the silt. Its basal gravel also underlies T2, from which we infer that the fan was twice terraced before the loessic silt was laid down, the later river level having coincided with the time of fluvio-eolian silt deposition.

The gravel underlying T2 and T3 differs from the older fan material by its gray color, which has a faintly pinkish tint, and by the perfect wear of its components. These are derived not so much from Murree sandstone as from Eocene and Mesozoic débris and a great variety of older rocks such as appear along the Tawi headwaters. This gravel is to be considered a second fan, which fills a deep and wide stream channel cut into the boulder fan. As in the Chenab outlet, its depositional surface marks the second terrace, while the lower river level is found at T3. Below, there is a prominent slope, 100 feet high, cut into the younger gravel by the Tawi River prior to the deposition of the lowest terrace (T4). This lower bench is made of loose gravel with shingle structure. The pebbles, in their order of abundance, consist of quartz, mica schist, quartzite, granite, slate, black chert, Murree sandstone, and Siwalik rocks. Boulders are present but distinctly fewer than in the other terrace formations. As on the Chenab River, a thin loam cover is found above the gravel. Downstream this terrace rests against Middle Siwalik beds, which also appear near milestone 166 on the road to Jammu.

The sequence of events as recorded by these basin deposits can be outlined as follows:

1. Deposition of a boulder fan (about 250 feet thick) and filling of a previously excavated basin under the influence of strong river action, intensified by normal faulting along the upper rim of the basin. This stage corresponds to glaciofluvial action in the upper Tawi tract during a general retreat of the second glaciers.
2. Slight dissection of the fan by degradation, resulting in T1. Weathering on the fan surface.
3. Strong entrenchment of the ancestral Tawi by over 400 feet and major dissection of the older basin deposits.
4. Aggradation of the stream and filling with boulder gravels. Deposition of pink silt, the greater portion of which was subsequently removed save for remnants on older fan surface (third glacial).
5. The Tawi cut the boulder gravel to level T3, on which it meandered freely for some time so as to form a wide stream floor.
6. Second great entrenchment of the river by some 100 feet.
7. Another aggradation and filling of the river channel by 60 feet of shingly gravel with loam cover.
8. Last trenching of this terrace to the present Tawi level.

In view of the concurrence of these stages with those found in the Chenab, Jhelum, and other Pir Panjal streams, it would appear that stages 4 and 7 are broadly to be correlated with the third and fourth glacial advances. No exact proof can be offered for this contention unless T2 and T4 are actually traced to their respective glacial deposits. However, this has been done on the Kashmir flank of the Pir Panjal and in the Poonch River tract. (See section E.) Also, the association of loessic silt with the second and fourth terraces is indicative of periglacial conditions, and this also substantiates our terrace correlations.

Lower Tawi tract above Jammu.—No data are available from the Tawi Valley below Udhampur save for the last 8 miles or so, where the main road to Jammu leads along the stream. In the intermediate region two or three terraces were observed in a tributary valley below Chanas (fig. 106). The stream is here deeply incised in a light-gray boulder gravel of great thickness. Its constituents are well rolled and composed mainly of hard rocks, such as quartz, quartzite, limestone, granite, gneiss, and dark igneous rocks. The first three give the gravel a light color, dazzling white in the noon sun, so that it contrasts strangely with the variegated shales and red beds of the Siwalik formations. As no igneous or metamorphic formations are known in this valley, it is somewhat puzzling to see so thick an accumulation of rocks otherwise characteristic of the Boulder conglomerate and its equivalents. Indeed, the headwaters of this river descend from a region immediately adjacent to the Udhampur Basin, and there is good reason to believe that these streams denuded the boulder fans which should extend westward along the border fault. Such extension was observed from a vantage point on the Jammu road below Udhampur. In fact, the prominent fault scarp continues westward, at least as far as Katra, and is interrupted only by a narrow low divide that separates the larger Tawi depression from the dissected basin drained by its tributary (fig. 106). In other words, the gravel fill can be derived only from the Boulder conglomerate, and it should therefore be of later age. This inference is confirmed by analysis of the ancient river levels. The widest is cut into the gravel and lies over 100 feet above the river. Far above appear terrace remnants underlain by the same gravel. These two levels can only represent T2 and T3, which, near Udhampur, are underlain by outwash material younger than the Boulder conglomerate. Locally there are remnants of a lower terrace, 50 to 60 feet above the stream level, which would correspond to T4. These ancient river beds can be followed for 5 miles downstream, to the junction with another Tawi tributary.

At Nagrota the main road reenters the Tawi Valley, and as the river here meanders freely over a wide flood plain, terrace records have become scarce. A low flat can be seen 30 feet above stream level, and on the left bank appear remnants of benches, apparently cut into Upper Siwalik beds. Four miles above Jammu the Tawi cuts across the Boulder conglomerate ridge mentioned above. With a prominent dip slope this ridge descends toward the alluvial plains of the Punjab (fig. 110 and pl. XXII, 4). Secondary rivulets with intermittent seasonal water supply dissected the tilted fan and gave rise to wide fans, choked with boulder débris. These fans occupy flat valleys entrenched into an old terrace

bench (T on pl. XXII, 4) of the Tawi Valley. This bench surmounts the Tawi by some 300 feet and might well represent T2. A second bench can faintly be seen down the slope, some 120 feet above the Tawi.

Terrace record and Pleistocene uplift of fans.—The presence of such terraces in a dissected and recently tilted fan is of special significance for our knowledge of growing structures in the Himalayan hills.

The middle Pleistocene age of the great fan formation having been established, it follows that the uplift took place since that time. This process, as the terrace levels indicate, was undoubtedly not continuous. The major terrace especially proves that the Tawi graded its course, and this would have been impossible had the ridge undergone continuous uplift. Hence the tectonic growth was intermittent, the upward movement being at times interrupted by quiescence. Under the assumption that the major level is T2, it would seem that a major portion of the uplift had taken place between the second and third glaciations. This was, as has already been demonstrated from Kashmir, a long interglacial period and

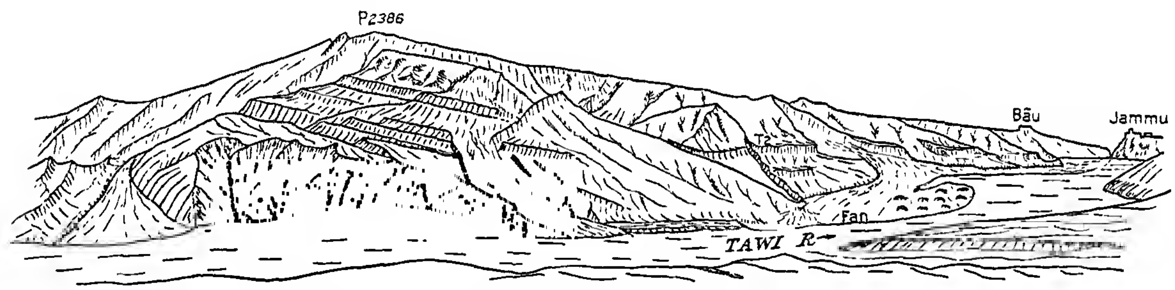


FIGURE 110.—View from Jammu road across Tawi River on tilted Upper Siwalik fan above Jammu. T2, terrace.

a phase of great erosion. As the difference in level between this bench and the crest of the ridge is about 1,000 feet, it is safe to conclude that the fan was moved upward by that amount within one interglacial period. This figure naturally does not take into account the decrease in altitude which the ridge must have undergone through subsequent erosion. Also the relative height of the ridge above the level of the Punjab plain (1,000 feet) exceeds, at places, 2,000 feet, so that the inferred figure for the interglacial uplift is a minimum, which can safely be enlarged to 1,500 feet. This very strong uplift was followed by quiescence, as recorded in the major terrace, but the quiescence in turn was followed by renewed dissection. This should have occurred after the third glaciation had excavated the fan down to the next terrace. Owing to the incomplete preservation of the lower terraces we cannot analyze this process further, but this much can be said: the subsequent uplifts must have been of lesser magnitude than the first middle Pleistocene deformation. If all four terraces were present, as in the upper valley, we might say that at least three minor uplifts had occurred. Indeed, if the present difference in height between the crest of this ridge and the plains (1,385 feet) is taken into account, we simply have to subtract from this the first minimum figure of 1,000 feet (second interglacial uplift) in order to get the total amount of the

later uplift. This is about one-third of the growth that took place in the second interglacial period, which may mean that the tilting was retarded in later Pleistocene time. But it is also possible that the upper Pleistocene time span was shorter than that of the middle Pleistocene, and if so, we could not expect an equally consistent record of tilting.

As a consequence of these recent movements the ancient terrace levels were tilted. The degree of tilting for the major bench is about 6°, as compared with the 10° dip slope of the Boulder conglomerate and the 2° gradient of the present stream. The point where the surface slope and the main terrace dip underneath the alluvium of the plains lies at the valley outlet near Jammu. Here there is in progress a new fan formation, which is greatly aided by the vast supply of boulders that are being washed out from the front ridge.

Considering that the Upper Siwalik beds in this region are composed of two fan accumulations—the Boulder conglomerate and Tatrot zone, of which the former overlaps the latter mountainward—it would seem that at present another large fan is being added toward the plains. In this arrangement is reflected the continued southward growth of Himalayan structure.

THE PLEISTOCENE DEPOSITS OF POONCH

By T. T. Paterson

The following notes are descriptive of a traverse from the north side of the Pir Panjal at the head of the Ferozepur Nullah down a tributary river of the Poonch, through the foothills to the plains. (See fig. 6.) The topography of this area has already been discussed in an earlier section.

The course of the Poonch River (fig. 111) can be divided into four parts determined by the geology and physiography of the regions through which it passes.

1. The high mountain tract is characterized by canyonlike valleys over 2,000 feet in depth with long flat-topped interstream divides running up into the 3,000-foot wall of the southern face of the watershed (fig. 117). In this part are congregated the moraines of the various glaciers. The first glacial moraines are now being denuded, the only evidence being the survival of truncated glacial troughs and a few scattered moraines along the crest of the main range. The second glacial moraines crown the high flat-topped ridges, and the later ice advances have plunged their moraines deep along the incised gullies.

2. The low mountain tract fringes the high tract and presents a rolling landscape with rounded hills and wide valleys (fig. 124). The difference is well marked at Mandi. Passing from the canyons of Loran and Palera the path to Poonch swings suddenly at Mandi into a broad, intensely cultivated valley, sweeping up into rounded crests. The greater part of the later glaciofluvial outwash is congregated here as high-level terraces "of unstratified or crudely stratified sand, gravel, shingle and still coarser" (Wadia, 1928, p. 287).

3. In the foothills the river has incised the meanders of a previous course into a series of parallel ridges lately uplifted. The deposits of this portion are the finer equivalents of the outwash of the low mountain tract.

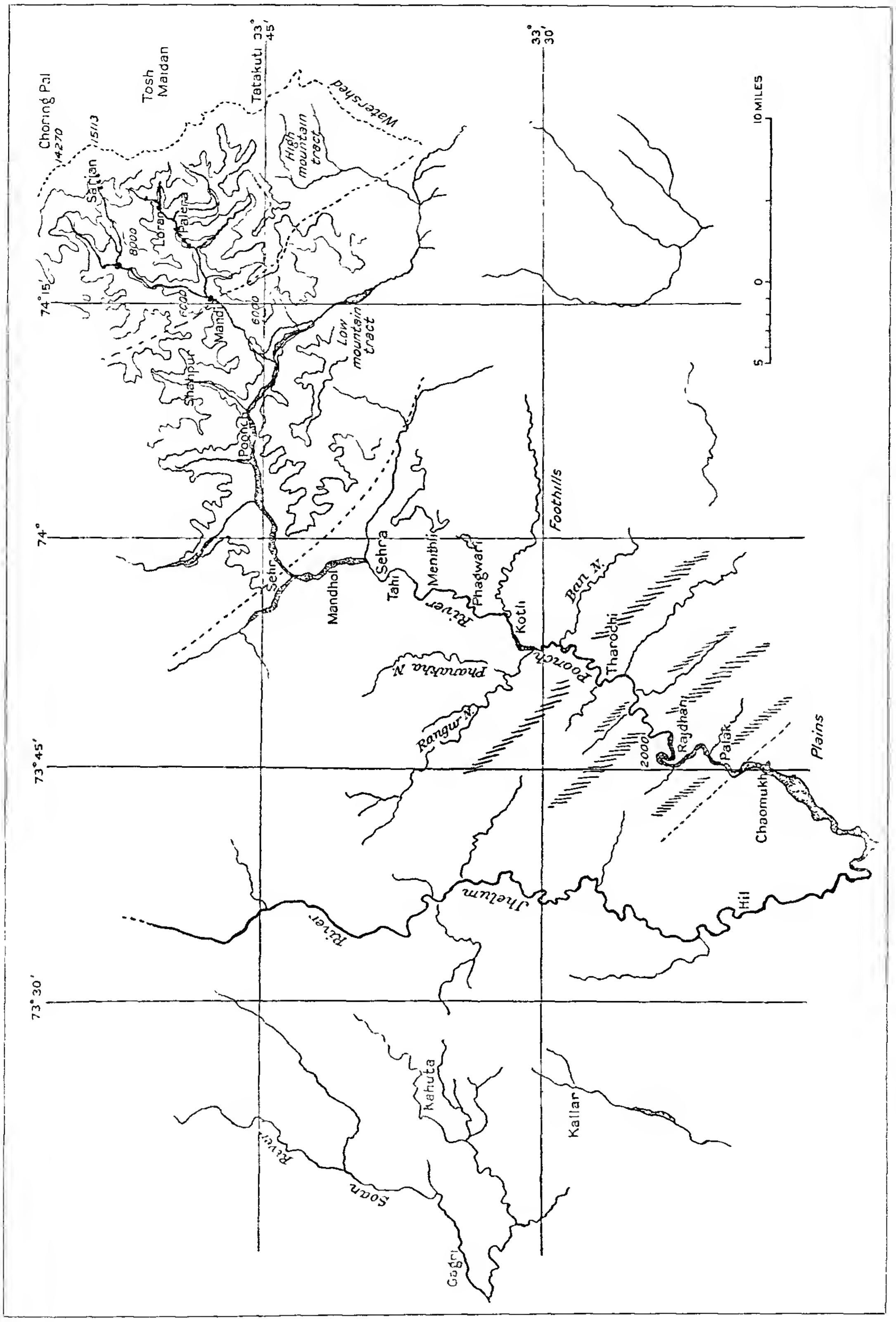


FIGURE 111.—Sketch map of the Poonch drainage basin, showing major physiographic divisions and Quaternary deposits.

4. The plain, from Palak to the junction with the Jhelum, is characterized by thick deposits of clays and loess. It has been formed within the basin of Chaomukh (figs. 140 and 141).

The High Mountain Tract

Figure 112 is a sketch of the country around Choring Pal, on the north side of the watershed. There is a striking difference between the "flattened" topography of the northern flank and the sharply incised, wind-battered southern flank. Northwest of peak 12,990, near Bodpathar,[1] lies a shelf on which moraine material still preserves its original topography to some extent. At A is a peculiar flattening of the valley wall like a terrace. At B, in the valley floor at 9,840 feet, is a high terrace of moraine matter with huge subrounded boulders in the river bed. At C, 11,000 feet, is a terrace of moraine débris, presumably that at B, and on it later terminal moraines. At 14,360 feet an old U form can be seen truncated by a U valley, so forming a hanging valley. The U form was still later cut by a cirque, which from its size and fresh character looks later than the second U valley. There are moraines in this cirque and in the U valley at the top, at nearly 13,000 feet.

Figure 114, a view toward peak 14,270 near Choring Pal, shows the remnants of two U valleys on the sky line. These are truncated by a transverse trough in which ice overflowed through a flattened U form in the direction of the observer. Moraines have been left in this trough. A deep cirque of later age has been incised into these two earlier forms. These several glacial features are related, in all probability, to the first, second, third, and fourth glaciations, as indicated in figure 114.

Figure 113, *a*, also on the northern flank, shows on the sky line the overflow ice channel from the large gathering ground of the Tosh Maidan into the head of the Ferozepur Nullah. This channel has been cut into a wide ridge, here interpreted as of first glacial age, with associated lateral moraines at an appropriate height, and lateral moraines of second glacial age lying in a hollow some distance beneath. A deep incision in second interglacial time left these moraines high above the present river, which flows in a trough of fourth age cut into a third glacial trough with morainic débris.

At Jamlanwali, in the same region, a moraine of similar appearance to that supposed to be of third age lies within a valley cut out of fan débris deposited in a valley form of the same age as that noted as second interglacial.

Figures 115 and 116 also illustrate some interrelationships of cirque formation and ice advances. A wide U trough proceeds from a group of cirques and is truncated by two later troughs which, on comparison with figure 113, seem to be of third and fourth age cut into second. These troughs are lined with ground moraines.

A large cirque has been cut from the second profile (fig. 116), and in the rock above has been formed another cirque, with moraines, M2.

A fairly wide U valley proceeds from the older cirque and terminates in moraines, a younger overlying an older. Perhaps the older one is a last moraine of the third glaciation, but from its height and size and comparison with general

[1] Refer to the appropriate 1-inch maps of the Topographic Atlas of India for places not indicated on figure 112.

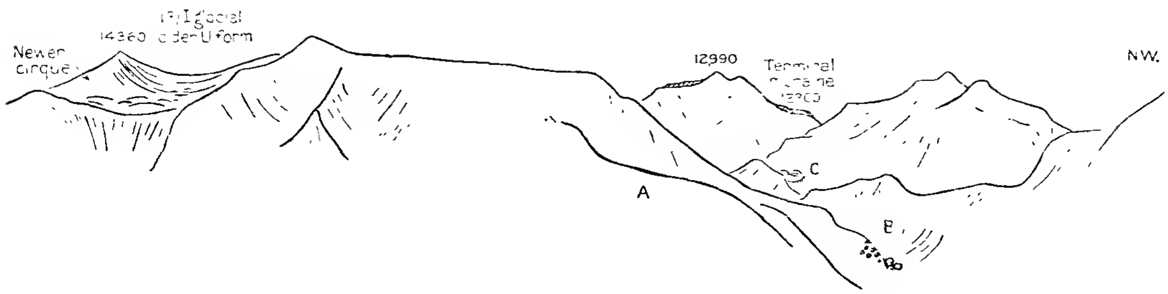


Figure 112.—Sketch of highlands on northern flank of the Pir Panjal near Choring Pal.

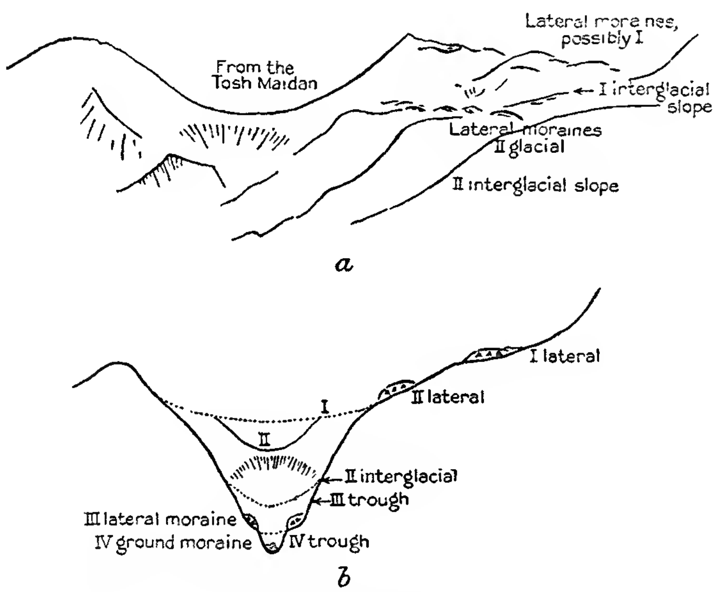


Figure 113.—*a*, View from Panjanpathat toward Tosh Maidan; *b*, Transverse section, upper Ferozepur Nullah.

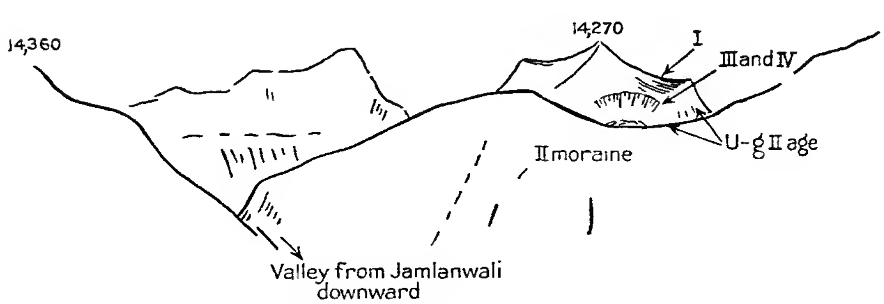


Figure 114.—View toward peak 14,270 of figure 111.

results elsewhere the younger moraine must be of fourth age, for the fourth glacier lay at much lower heights than the final stages of glaciation, which may conceivably be represented by M6 and M4 with later phases, M1, M2, M3, and M5 (fig. 115). Certainly these last-named moraines cannot have been formed under present-day conditions with the height of the snow line 2,000 to 3,000 feet above.

Figure 117 is a sketch of the watershed and part of the high mountain tract from Tatakuti eastward. This intensely rugged slope is in pronounced contrast to the more gentle widely incised slopes of the north (pl. XIII). Very outstanding are the overdeepened cirques of wide extent, cut into by a series of smaller ones of late date. These wide cirques were produced originally by the very extensive second glaciation, which, as shown later, produced the moraines of the inter-stream divides. The remains of the first glacial troughs at high levels are indicated by the appropriate symbol. At A a deep trough cut into the second cirque carries on its flanks morainic débris which is eroded several hundred feet, with production of a valley, glaciated and carrying moraine of fourth glacial age. Moraines of a similar fairly youthful topography can be seen at B, C, and D, extending as much as 3 and 4 miles down the valley. But they are not so fresh as a group of moraines clustered near the mouths of small cirques of distinctly more modern character. The major dissection of the large second cirques was due to long erosion during second interglacial time, and the general appearance of this southern face is that of a steeply inclined slope exposed to all the force of monsoon precipitation, deeply dissected, glaciated, again subjected to rejuvenation of erosion, and again glaciated.

The relations of the later glaciations are well expressed by figure 118, showing sections above Sarian. There is a very fresh moraine at 11,500 feet which has the same appearance as the moraines fronting the newest cirques of figure 117 and is interpreted as of fifth age. It overlaps two older terminal moraines (fig. 118, *a*), of more mature topography, damming back a tarn, which is 500 feet lower down. These moraines were laid down in a valley cut out of moraine and glaciofluvial material, of third age, and this is so thick that the valley, over 400 feet in depth, is still cut into it. Figure 118, *b*, a section still lower down, shows that this third glacial material once filled the whole of a deep steep-sided valley, eroded during second interglacial time into a more mature surface of which little remains except small flattened ridge tops. The third glacial deposit, though filling most of the valley at Sarian, is no longer a ridge at Mangiana, a little lower down, but becomes a terrace composed of glaciofluvial outwash and a little morainic débris, probably ground moraine originally. At Sarian the ridge feature of figure 118, *b*, is determined by lateral third interglacial erosion, and in the valleys so formed the fourth ice advance deposited outwash. These deposits in turn have been eroded probably during a wet period immediately following fifth glacial time.

At Loran there is a more complete exposé of the succession (fig. 119). At 8,000 feet there are remains of an old land surface with gravels and coarse detritus, then there is a steep slope to the highest terrace, here almost 1,000 feet above river level. It is erosional, cut out of the rock, and is fairly constant. It is thoroughly dissected, and remains of it stand out as ridges. If the main valley deepening is

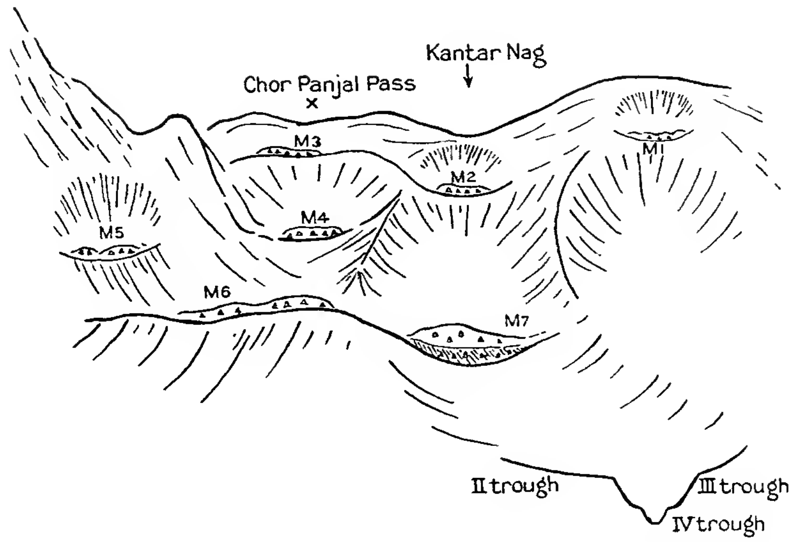


FIGURE 115.—View from point above Choring Pal toward the Chor Panjal Pass.

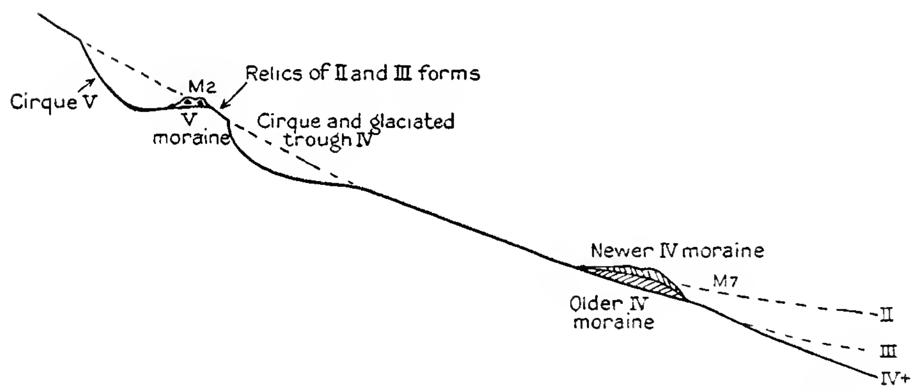


FIGURE 116.—Diagrammatic section of cirque and moraine relations above Choring Pal.

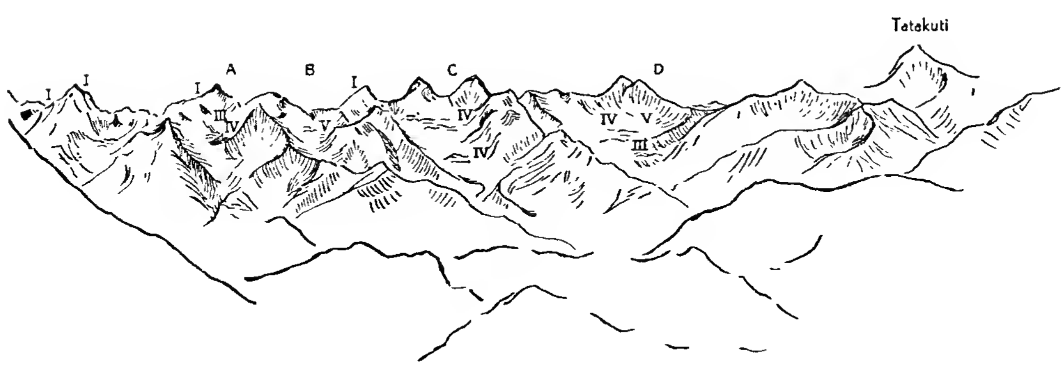
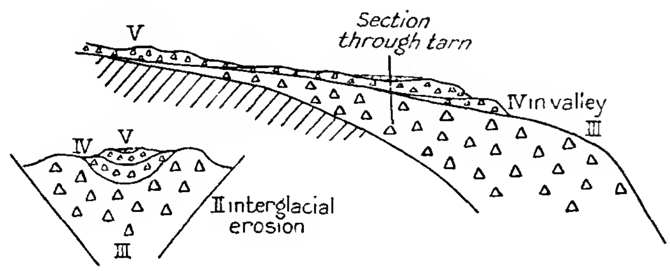


FIGURE 117.—View of the watershed east of Tatakuti, from Shahpur. See text for explanation.

second interglacial, perhaps this terrace, T1a, was cut not long after the second glaciation, even part of it formed during a final retreat stage, the later interglacial erosion T1b (fig. 121) giving the greater steepening to a deep trough in which was deposited over 500 feet of third glacial morainic and glaciofluvial matter that was subsequently terraced.

This terracing is somewhat complicated owing to the proximity of the glacier front. The terrace at 500 feet is very inconstant and irregular and was probably formed during a retreat stage of the third glacier. Far more constant is the wide main terrace at 400 feet, which is of third interglacial age and erosional. The next



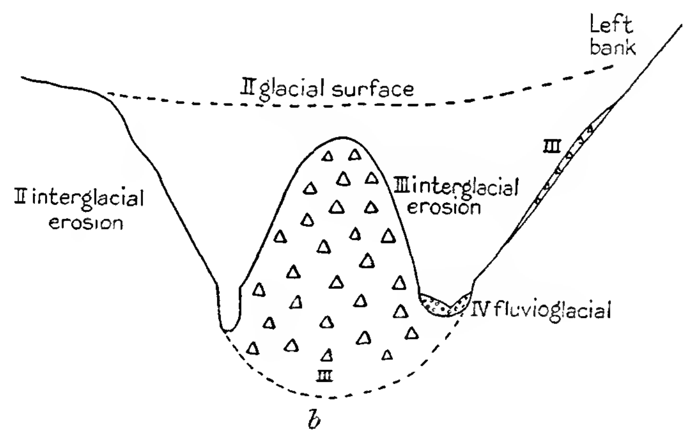


FIGURE 118.—Sections above Sarian.

terrace can be traced into the fourth glacial moraines, and the succeeding one is probably of fourth interglacial age, followed by another cut of fifth glacial age.

The more purely glaciologic side of this problem can be expounded by a section at Bara Chhari (fig. 120), between Loran and Palera. Below a detritus-covered surface at 7,500 feet is an erosional surface at 7,000 feet. This could be correlated with the constant surface noted above as of very early second interglacial or even very late second glacial age. From it descends an oversteepened side wall, which, on the left bank, is interrupted by a roche moutonnée form backed by moraine, presumably a lateral deposit of the third glacier. The moutonnée form is carried steeply down into the valley, which shows a U-shaped trough, and on this a main terrace is formed of ground moraine and glaciofluvial detritus. On

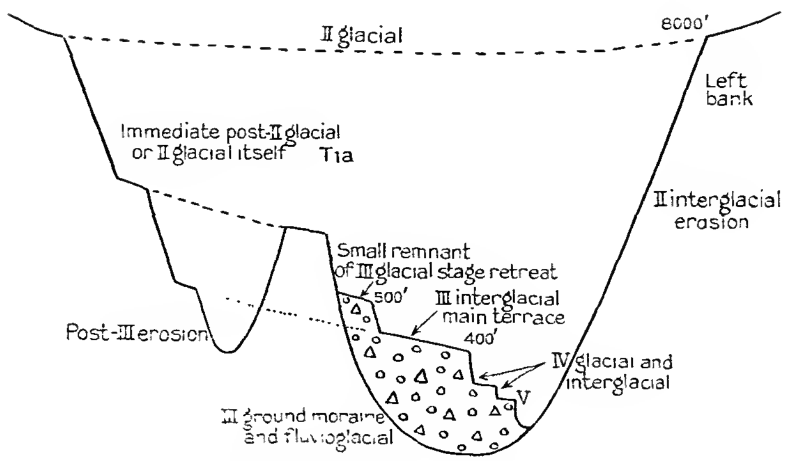


FIGURE 119.—Transverse section at Loran.

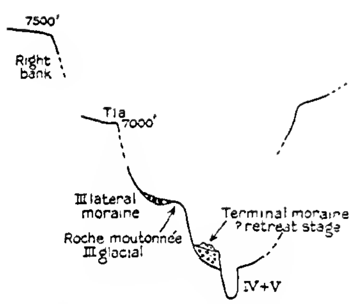


FIGURE 120.—Transverse section between Loran and Palera.

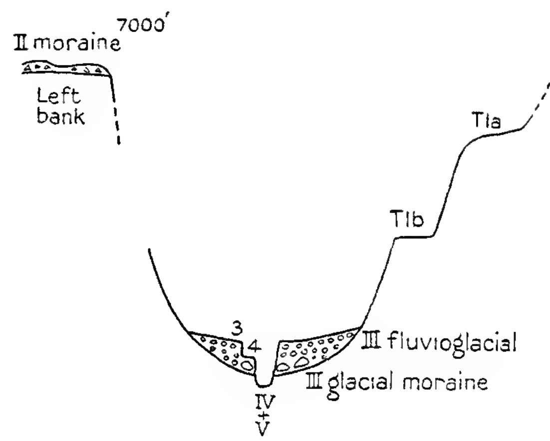


FIGURE 121.—Transverse section at Palera.

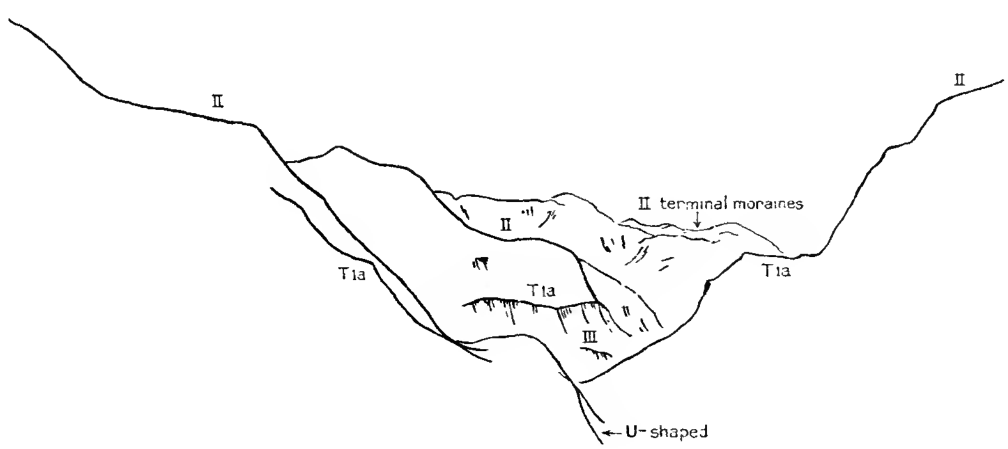


FIGURE 122.—View toward Palera from Loran. See text for explanation.

top of this rests a terminal moraine with a weathered aspect which may indicate its age to be third glacial or a retreat stage of the third, especially as it is known that the fourth glacial moraines are confined to higher portions of the stream bed. Moreover, the underlying material and even the rock have been gullied, probably during the fourth and fifth stages.

Still lower downstream, at Palera (figs. 121 and 122), moraines of second glacial age lie 2,000 feet above the valley floor with typical hummocked appearance. Such moraines, now well covered by vegetation and almost obliterated by digging, have been observed by Wadia (1928, p. 288). In the valley itself there are terraces T1a and T1b and a deep third glacial trough with ground moraine and conglomerate. Two terraces are cut out of the conglomerate, which at one point overlies a belt of boulders that could only mean the former presence of a terminal moraine.

Between Palera and Mandi, in the Rajpur Gorge, the third glacial oversteepening is confined to a smaller portion of the second interglacial erosion valley, indicating that the ice was losing its intensity of erosion (fig. 123). Between Rajpur and Loran occur several belts of moraine within the third glacial trough at heights of 4,900, 5,200, and 6,000 feet. A still lower one, the lowest, can be found just below Mandi at 4,500 feet, marked by a great number of enormous erratic boulders in one spot.

The Low Mountain Tract

The topography changes at Mandi. The hillsides are no longer scarred and rugged, nor are the slopes so densely forested (fig. 124). There are no signs of alpine sculpturing such as occurs only 2 miles up from Mandi. The valley widens to over half a mile, and more than 200 feet of glaciofluvial outwash was deposited in it. This outwash is finer toward the top, no doubt owing to retreat of the third glacier. The outwash can be traced downward and becomes progressively more fluviatile, forming the terraces which must therefore be of later than third glacial age.

The side valley of Shahpur yielded some interesting data. Here there is the strong second interglacial erosion of T1b, following a steep cutting of T1a. The valley of T1b is filled up to 250 feet with compact fluviatile gravels, which are thoroughly dissected and twice eroded to form terraces. At the base of the T1b gravel occur large boulders of foreign provenance—Panjal trap, schists, and graywackes—which are difficult to explain in this side valley other than by assuming that originally the second glaciation spread them over a little-dissected surface that only subsequently was eroded to its present form. The presence of these erratics in small side valleys of the low mountain tract is very common.

The town of Poonch lies in a rather wide valley conspicuous for its great development of terraces in the western parts. Figure 125 gives a generalized diagram of the terrace system. It seems that the valley was filled to a depth of 200 feet with third glacial detritus which was then eroded to about 120 feet.[1] Another period of erosion was followed by deposition to 70 feet, probably in fourth glacial time. A low terrace may be fifth.

[1] This is the younger gravel fan of the Chenab and Tawi valleys, described above.

Surrounding the valley are long, steep slopes to 700 or 800 feet, then long slowly rising ridges lead to the highest points. These may represent stage T1a, as also the platform at regular intervals in the small side valleys, indicating another halt. Therefore it would seem that the Poonch Basin was in first interglacial time a broad, very shallow valley. The second glacier then covered the ground to a limit now represented by the 7,000-foot contour. The glaciofluvial outwash of this glacier must have been deposited in such broad, shallow valleys and subsequently

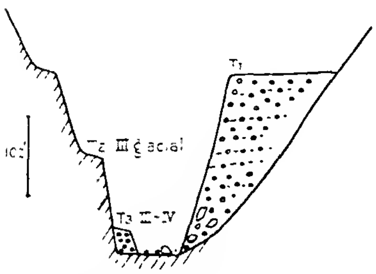


FIGURE 123.—Transverse section of Shahpur Nullah.

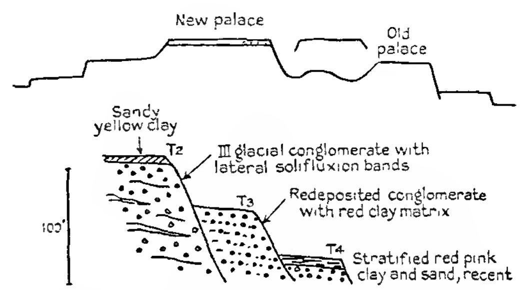


FIGURE 125.—Transverse section at Poonch. T2, T3, T4, terraces.

FIGURE 124.—Rounded topography about Shahpur.

removed by intense erosion. From the ¼-inch map it would appear possible that during second glacial time the drainage was rather different, being directly southwest along broad valleys and hillsides, and may have been caught in the trough bounded on the south by the first northwest-southeast ridge of the Jhelum syntaxis—that is, the Kotli syncline.

At Sehr (fig. 126) the old erosional floors are well exposed—the second interglacial, cut within 60 feet of present river level, and the third interglacial, cut

within 15 feet, with subsequent deposition of the T3 gravels, probably of fourth glacial age. This was eroded and gravels of T4 laid down. There are some large boulders, as much as 6 feet long, of foreign origin. It seems almost impossible that such large blocks could have been brought there by the same agency that deposited the rest of the gravels. However, some boulders were derived from preexisting second glacial levels, as at Shahpur.

THE FOOTHILLS

Between Sehra and Palak the river cuts across a series of parallel ridges incising preformed meanders into them, even on the crests. The terraces are well developed throughout this region, as figures 127–132 indicate. Comparison of heights of terraces shows some distortion of the upper terrace levels in those parts of the valley that cut the ridges, evidence of movement within this area into late Pleistocene time. An accurate study of this matter is left to a future publication.

The figures mentioned show that before each depositional cycle the bed was eroded to rock bottom. Further evidence for the age of T3 was found at Mandhol (fig. 127) in the presence of a boulder of partly cemented conglomerate of a kind seen in the third glacial terrace between Palera and Loran. On the heights above Sehra (fig. 128), 400 feet above river level, was found a conglomerate of foreign boulders as much as 3 feet in diameter, some subangular, faceted, in a brownish-pink clay matrix, unlike the conglomerate of the third glacial terrace, 300 feet below. The boulders also show greater heterogeneity of size. There are three possibilities:

(*a*) That the material is of third glacial age, despite the difference of facies below and above. This would mean that the valley was filled with 400 feet of glaciofluvial outwash, coarser at the top, and that erosion after third glacial time removed 300 feet. In support of this is the fact that the conglomerate is plastered against the hill slope behind Sehra.

(*b*) That the material is second glacial (faceted boulders), which would mean that the second glacial valley floor has dropped from 6,500 feet at Palera to 2,750 feet here, and also that the erosion of second interglacial time, represented by 2,000 feet at Palera, is here only 400 feet.

(*c*) That the conglomerate is redeposited second glacial material on an erosion platform of very early second interglacial age corresponding to the halt stage at Loran (fig. 119).

It seems impossible that the third glacial outwash, which could produce only 200 feet of conglomerate at Mandi, next to the glacier snout, could deposit 400 feet here, where there is no sign even of extensive synclinal development. Nor could erosion after third glacial time remove at this point 300 feet of gravels when evidence of such erosion is not found even in the high mountain tract. Either of the two other possibilities can hold, but the age of the material, if (*c*) is correct, would not be far removed from second glacial. Hence the second glacial valley system was already well established and had cut down into the rising chain of hills. Further proof comes from Purl, below Tahi, where the high-level conglomerate occupies

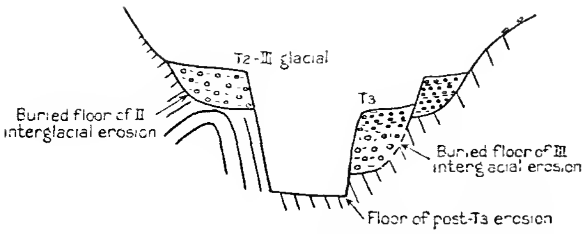


FIGURE 126.—Transverse section at Sehr. T2, T3, terraces.

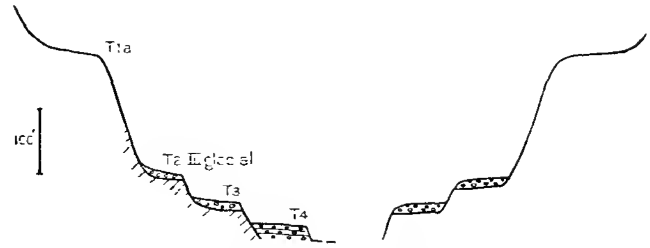


FIGURE 127.—Transverse section at Mandhol. T1a, T2, etc., terraces.

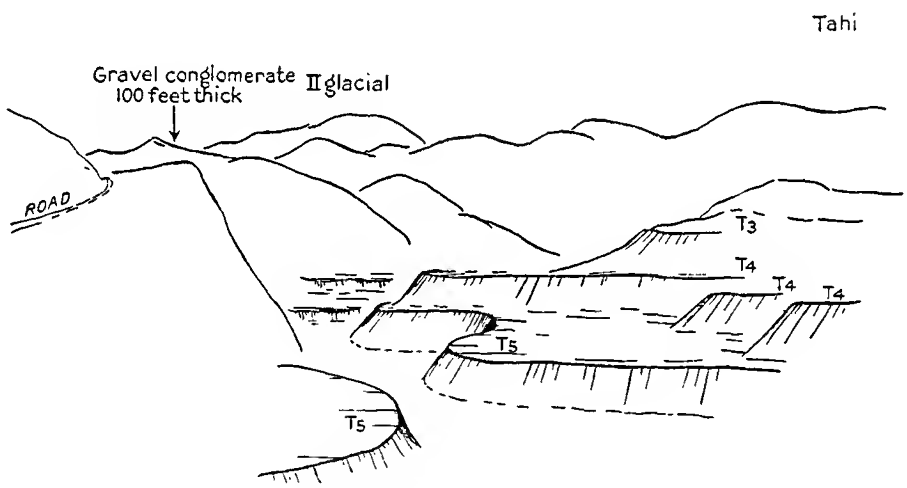


FIGURE 129.—Terrace landscape at Tahi.

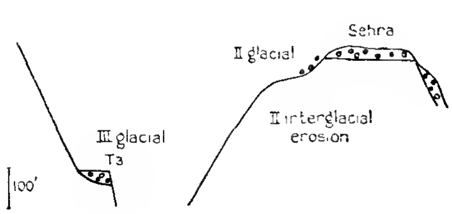


FIGURE 128.—Transverse section at Sehra.

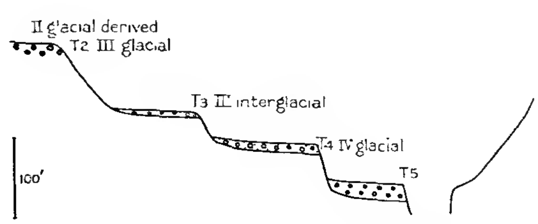


FIGURE 130.—Transverse section at Tahi. (See fig. 129.)

an old river channel—a wind gap—isolated when the river, cutting deep during second interglacial time, deserted this channel and eroded elsewhere. Still farther down, at Menithli (fig. 131) this high level conglomerate lies almost 200 feet above a terrace which, because of its height above the 100-foot terrace which is third glacial, is equated with the second interglacial erosion cycle.

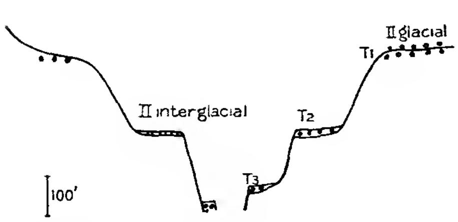


FIGURE 131.—Transverse section at Menithli. T1, T2, T3, terraces.

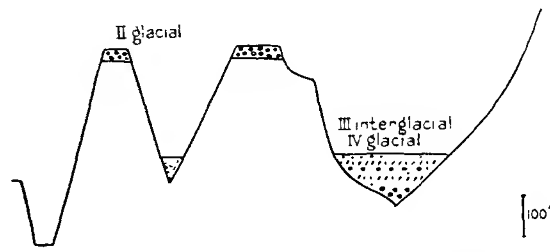


FIGURE 132.—Transverse section at Phagwari.

At Phagwari (fig. 132) two plateaulike remnants of second glacial conglomerate are left 500 feet above the river. In the valleys between are fluviatile deposits of local Murree sandstone, little transported. This corresponds to the capping of T4—that is, third interglacial and fourth glacial.

The Kotli Syncline

The Kotli syncline, "key area of the Poonch Siwaliks," has been described in a general fashion by Wadia (1928, p. 277). Outliers of Boulder conglomerate belonging to the Upper Siwalik beds form a series of hillocks to the east and west of the town of Kotli, which stands on the river. Immediately opposite the town

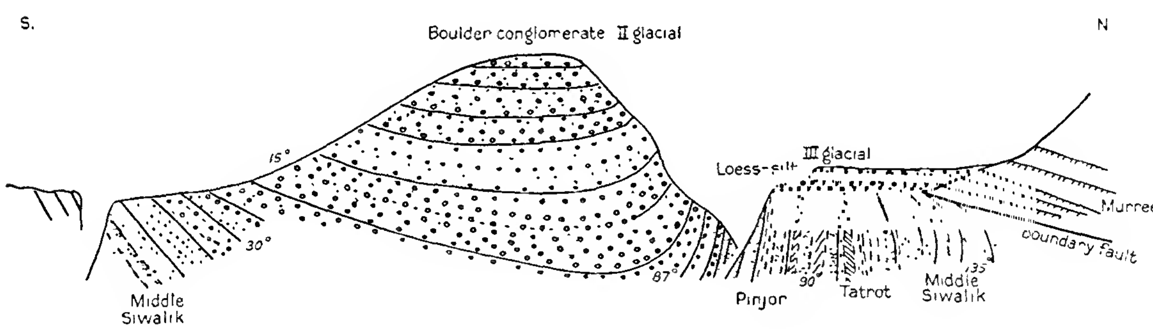


FIGURE 133.—Transverse section across Kotli syncline at Kotli.

the section shown in figure 133 is magnificently exposed. On the northeast the hills of Murree sediments, purple and red, overran the Siwalik beds along the main boundary fault, which, as Middlemiss has shown, dips 12° NE. The Middle Siwalik deposits consisted of gray-green friable sandstones and red and yellow clays. The Tatrot beds succeed them by conformable overlap and are similar, with a greater development of sandstones and with a series of massive pebble beds in which the pebbles, 3 inches or less in diameter, are foreign to the area as in the Boulder

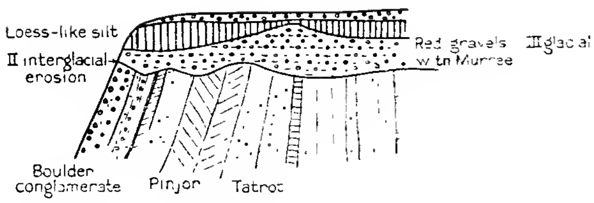


FIGURE 134.—Exposure in Phanakha Nullah, west of Kotli.

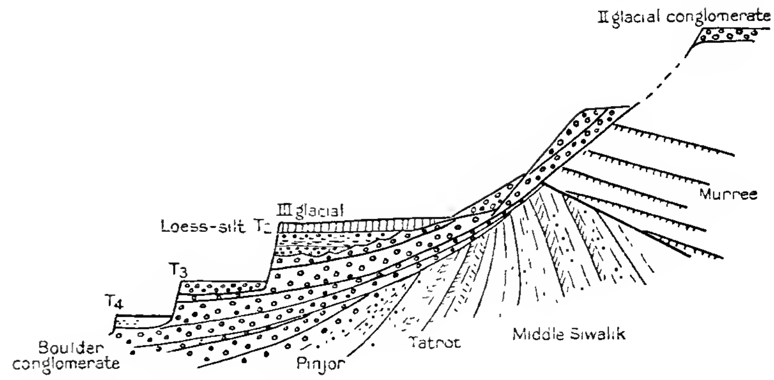


FIGURE 135.—Section of northern border of syncline at Dhangrot, east of Kotli.

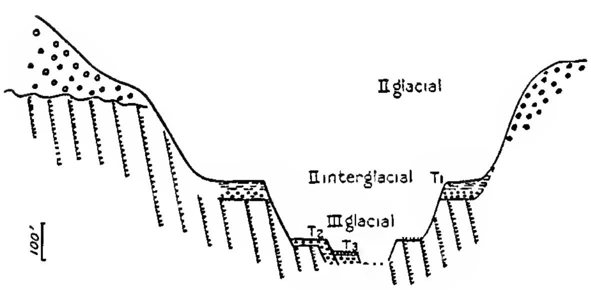


FIGURE 136.—Transverse section at Rajdhani. T1 T2, T3, terraces.

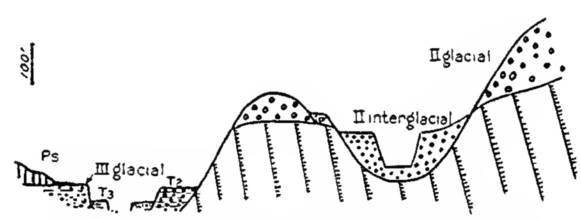


FIGURE 137.—Section at Palak. Ps, Potwar silt; T2, T3, terraces.

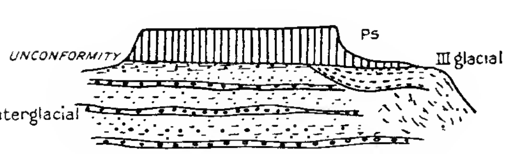


FIGURE 138.—Section in gully opposite Chaomukh. Ps, Potwar silt.

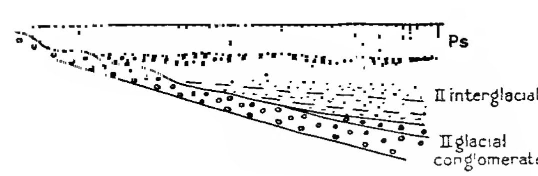


FIGURE 139.—Section on northern border of Chaomukh syncline. Ps, Potwar silt.

conglomerate, mainly Archean and Paleozoic rocks. The Pinjor beds are mainly clay (chocolate brown and pink), with hard, compact, light cream-colored sandstones and brown silts showing calcareous bands, some of them greenish. These green and gray sandstones of the Tatrot and Pinjor series in many places contain Murree derivatives.

The Pinjor beds pass conformably up into the Boulder conglomerate through light-gray sands with subangular grains, merging rapidly into true conglomerate that consists of well-rounded boulders as much as 4 feet in diameter. The largest boulders are commonly faceted and consist of pink, green, and white quartzites, porphyrites, Panjal trap, limestone, yellow and red sandstone, and Murree rocks. The matrix of the lower beds is a light-gray sand like that of the top of the Pinjor beds. The matrix of the upper beds is reddish-brown sand and not so extensive.

The syncline is not very broad but is deep and asymmetric, with steepening toward the faulted zone, as would be expected. Here the Middle Siwalik beds are definitely inverted; the lower beds of the Tatrot zone are tilted more than 90°, and the Pinjor is mostly vertical. The lowest layers of the Boulder conglomerate are almost vertical, but the upper layers are almost horizontal, showing that there was continuous deposition of the conglomerate while the syncline was deepening.

Erosion subsequent to the formation of the Boulder conglomerate has removed much of it from above the boundary fault, but at the hamlet of Dhangrot, immediately east of Kotli, there remains enough to show the relation of the Boulder conglomerate to the fault (fig. 135). Here again there is the successively conformable overlap of Tatrot, Pinjor, and Boulder conglomerate. But in its upper beds the conglomerate overlaps the fault. Hence there has been no thrusting in late Boulder conglomerate time, at least. Above the river at 500 feet occurs a high-level conglomerate terrace of the type which has been seen to be of second glacial age. It can be observed from figures 133 and 135 that this conglomerate would be continuous with the upper horizontal layers of the Boulder conglomerate, which contains faceted boulders and has exactly the same appearance. Hence it may be assumed that the upper layers of the Boulder conglomerate are of second glacial age and were deposited by the Poonch River, already with a distinct drainage pattern, of which the Phanakha Nullah is part. Further study of the problems raised by a survey of the Kotli Basin lies in the domain of tectonic research.

It was the second interglacial erosion which removed a great part of the conglomerate overlapping the fault, and on the eroded surface were deposited gravels, chiefly of local Murree rocks, with some derived conglomerate, and a thick layer of loesslike silt. These beds are slightly warped and can be seen opposite Kotli (fig. 133) and in the Phanakha Nullah west of Kotli (fig. 134), where there is a strong unconformity and where at the same time the conformable relation of Pinjor and Boulder conglomerate is excellently exposed.

Farther downstream, at Rajdhani, the second glacial conglomerate is well developed, and there is a greater thickness of the loess silt associated with the third glacial gravels of T3. The Boulder conglomerate, with a greater quantity of red sandy matrix like that of the upper layers at Kotli, lies completely unconformably

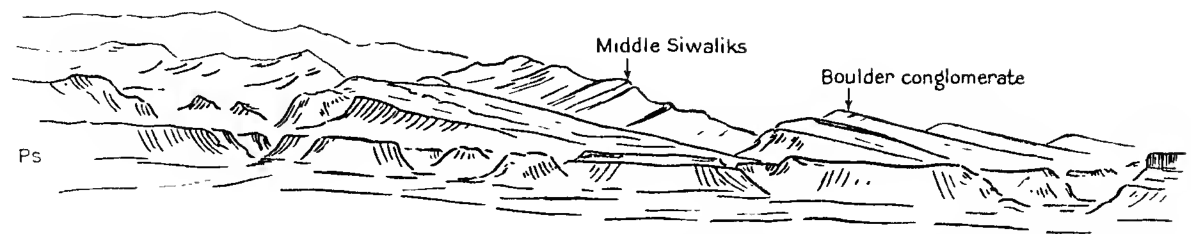


FIGURE 140.—View from the rest house at Chaomukh to the east, showing the topography produced by unconformable overlap and folding. Ps, Potwar silt.

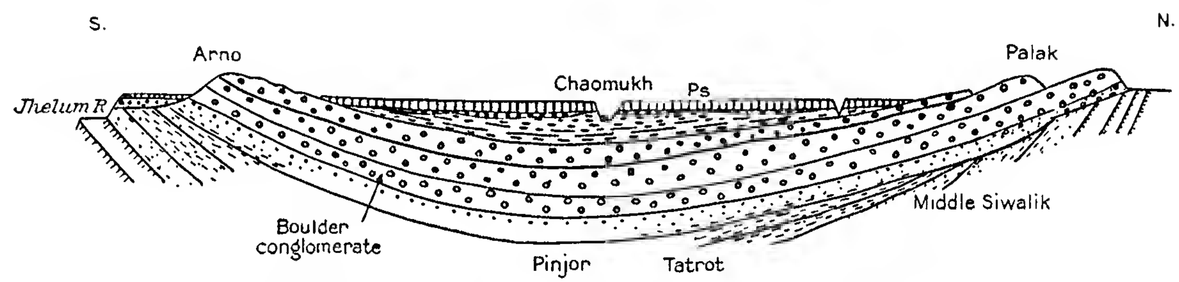


FIGURE 141.—Transverse section of Chaomukh syncline. Ps, Potwar silt.

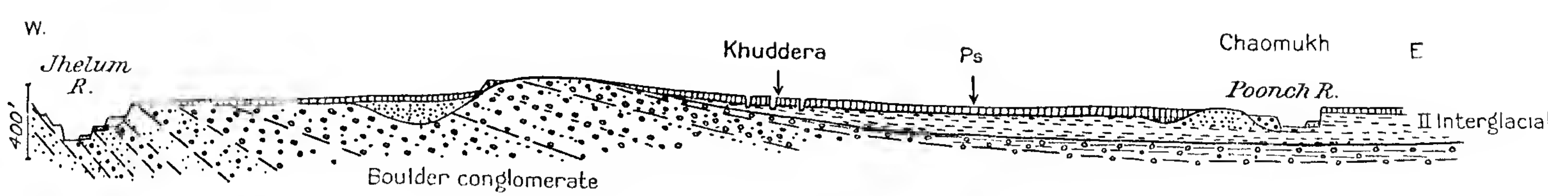


FIGURE 142.—Longitudinal section of Chaomukh syncline. Ps, Potwar silt.

on Lower Siwalik beds and is continuous to Palak, where it is unconformable to vertical Middle Siwaliks (figs. 137 and 141) and can be seen to be continuous with the massive Boulder conglomerate that underlies the Chaomukh syncline—further evidence supporting the hypothesis that the Boulder conglomerate is second glacial.

The Plains

Figure 140 is a view from the rest house at Chaomukh looking east and showing the unconformities between the Middle Siwaliks and the second and third glacial deposits. Here in the broad plain there is a great development of the loesslike silt, which is the Potwar of the Soan Valley. It overlies (fig. 139) a cemented conglomerate that lenses out within a short distance and is disconformable to a series of warped and well-bedded gravels and sands derived mainly from the Boulder conglomerate. These gravels are here interpreted as second interglacial, laid down in the developed basin of the Boulder conglomerate already eroded during a period immediately prior to their deposition. They may well represent the deposition

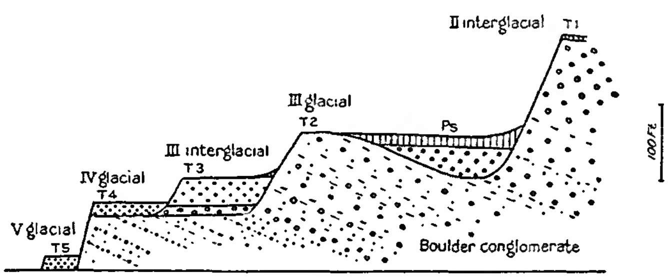


Figure 143.—Section of terraces (T1, T2, etc.) at Hil, on the Jhelum. Ps, Potwar silt.

phase of the long second interglacial erosion cycle, which along the higher parts of the river is represented only by erosion surfaces. The third glacial beds and Potwar silt are also slightly warped.

Sections of the Chaomukh syncline (figs. 141 and 142) are self-explanatory and show the asymmetry from north to south, with the great thickening of second glacial material toward the Jhelum River, which is the main outlet of this part of the Himalaya. Here the terrace system is more fully developed than on the Poonch, where the size of the valley did not allow such development except in the upper reaches. At Hil (figs. 143 and 144) there is a system of five terraces. The Potwar silt occurs on T2, as on the Poonch River; hence it can be assumed that the thick gravels of that terrace are third glacial, and, by analogy with the Sind of Kashmir, T3 would be third interglacial (note the deeper erosion escarpment), T4 would be fourth glacial, and T5 fifth glacial.[1]

Figure 145 presents a summary of these notes showing the relations of the various glacial episodes. The first glaciation is represented only by truncated U troughs and old moraine remnants on the highest part of the Pir Panjal water-

[1] Note the close agreement of this terrace analysis with that given by De Terra in previous chapters.

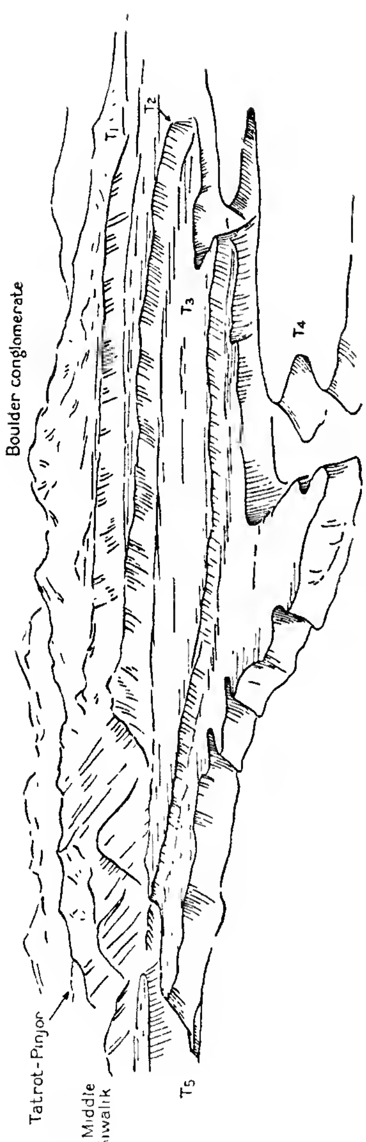


FIGURE 144.—View of the Jhelum terraces (T1, T2, etc.) at Hil, looking east from a point opposite the village.

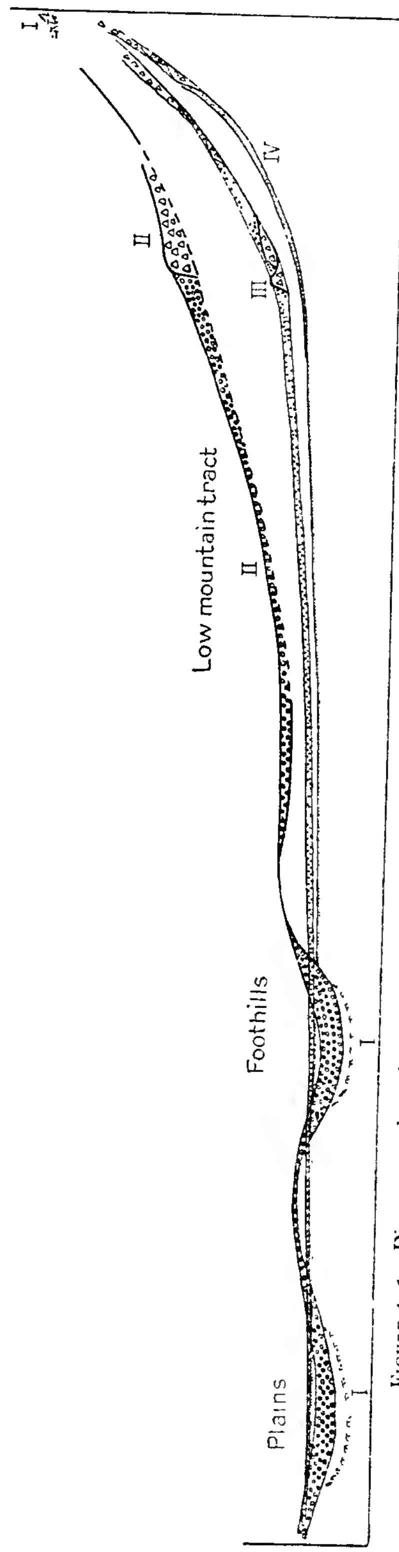


FIGURE 145.—Diagram to show the relations of the several glacial epochs (I, II, etc.) in different parts of the Poonch thalweg.

shed. Probably in first glacial time the mountains, which were subsequently elevated, were unable to sustain a major glaciation. The representative of this glaciation in the foothills is possibly the heavy gravel bed carrying many foreign pebbles, at the base of the Tatrot. There are other reasons for correlating the Pinjor with the first interglacial Upper Karewa beds of Kashmir. (See part II.)

Rapid uplift toward the end of this period produced erosion, which is reflected in the lower layers of the Boulder conglomerate at Kotli. Then the onset of the second glaciation increased this erosion, which had already incised to a great extent the Poonch drainage system, into which poured the outwash of the second glacier.

Contemporaneously the various foothill synclines were deepening; hence the thickness of deposits there and the overlap of successive beds. The increased height of the Pir Panjal, exposed to the full force of the monsoon, produced extensive moraine belts now isolated at about 7,000 feet or interstream divides formed by the erosion of second interglacial time, which was consequent on the uplift. This erosion cut down as much as 2,000 feet in the mountain tract, but the deposition phase is represented at Chaomukh. Movement continued into third glacial time, as warping of these last deposits indicates.

A deep valley system having been incised and a tremendous gradient established toward the watershed, the third glaciers advanced deep down this system and formed terraces traversing the warped earlier deposits in unconformable manner. There were later ice advances of no great consequence along a channel eroded out of third glacial material.

F. THE KASHMIR PLEISTOCENE IN ITS RELATION TO THE VALLEY BASINS OF THE UPPER INDUS DRAINAGE SYSTEM

The reconnaissance of the Pleistocene history of the Kashmir Valley can be properly evaluated only if we can show that the geologic records are not peculiar to this region but that they can be found also in neighboring areas. In the foregoing chapter, an attempt was made to correlate the stratigraphic sequence of Kashmir with that found in the foothills of the Pir Panjal. In this we were greatly aided by the fact that the glaciated tract merges into the nonglaciated region of the plains, in which fossiliferous Upper Siwalik beds are present. Indeed, the fossil and stratigraphic records of the Siwaliks, as worked out mainly by various members of the Geological Survey of India, provided a certain standard by which we could measure the correctness of our interpretation. This is especially apparent in the correlation of the Boulder conglomerate zone with the second glaciation, the conglomerate lying unconformably on tilted beds that contain an early Pleistocene fauna.

As we turn from the Kashmir Valley northward to the high Himalaya of northern Kashmir (or Indian Tibet), we can evidently not expect such favorable premises as the foothills offer. Siwalik beds are here unknown, and what fossil records the Pleistocene may contain cannot help much in the matter of detailed

correlations. For this purpose there are at our disposal previous observations on glacial morphology and sedimentation. But it should also be remembered that the main Himalaya around the upper Indus belongs to the same tectonic unit as Kashmir. This means that the geologic records of diastrophism found in the southern country can also be expected in the northern areas. The succession of events, in Pleistocene records, must in these regions generally be identical.

The data available from the upper Indus region were collected by many travelers, especially by Godwin-Austen (1862, 1880), Lydekker (1883), Oestreich (1906), Dainelli (1922), and Trinkler (1932). In addition I (1934, 1935) studied many of the Pleistocene sequences found at Kargil, in the Indus Valley, and at Lake Panggong, near the boundary of Tibet. Of the studies by the above-named scholars, Dainelli's deserve special consideration, since it was he who analyzed Himalayan glaciations more carefully than any of the others. Hence, it is only fitting that we consider his interpretations before we give our view of the Ice Age in this area.

DAINELLI'S ANALYSIS OF THE HIMALAYAN ICE AGE

A very brief review must suffice for our purpose. Dainelli's main conclusions (1922) may be summarized in the following manner:

Fourth glaciation (post-Würm I of Alps): Weakest of Pleistocene ice advances, though relatively strong in the Pir Panjal. Snow line in Kashmir at 3,800 meters. Thick outwash deposits in upper Indus at Skardu, but no glaciation in Indus Valley proper. Major depressions such as Kargil and Panggong basins ice-free. Plateaus of Deosai, Rupshu, and Depsang not glaciated. Of the total Indus drainage basin 20 per cent was glaciated during this period, as compared with 10 per cent today.

Third interglacial stage: Erosion of older lake sediments in Himalayas. Uplift of Pir Panjal, with folding of Karewa beds and tilting of Pleistocene in neighboring Punjab. All major valleys ice-free.

Third glaciation (Würm of Alps): Snow line in Kashmir at 3,500 meters. Glaciers did not reach Kashmir Valley. First terracing on Karewa beds. Skardu Lake, in Indus Valley, dammed by tributary glacier. No glacier in Indus Valley. Lakes in Baltistan, in Indus Valley near Leh, and in Changchenmo. Plateaus of Deosai and Rupshu only thinly glaciated. Tibetan plateau (Depsang) ice-free except for small local glaciers. Of total Indus terrane 30 per cent was glaciated.

Second interglacial stage: Erosion in mountainous tract. Possible extension of Karewa lake sedimentation in Kashmir.

Second glaciation (Riss of Alps): Snow line in Kashmir probably at 3,000 meters. Glacier snouts terminate at shore of Karewa Lake. Drift ice transports boulders through Jhelum Gorge to Rampur. Karewa lake beds. Little glaciation in Pir Panjal. Indus Glacier extends to plains of northwest Punjab, where periglacial lakes receive drift ice with erratics enclosed. Strong glaciation all over Himalaya and Karakoram. Tibetan plateau (Depsang) locally glaciated but mainly free from ice. Rupshu and Depsang plateaus ice-covered. No continuous Indus Glacier after this stage. Of total area 50 per cent was glaciated.

First interglacial stage: Uplift of Pir Panjal, thereby damming Karewa Lake, which developed an outflow in an old course of the Jhelum near Baramula. Great erosion, following uplift; entrenchment of all rivers, especially of Indus at Skardu. Early Karewa lake beds.

First glaciation (Mindel of Alps): Intensive glaciation on main Himalaya but little if any in Pir Panjal. Advance of ice into Kashmir Valley notably through Sind and Liddar glaciers. Ice cover on Rupshu and Deosai.

Dainelli's correlation of this Himalayan glacial cycle with that of the Alps is tentative. He apparently considered his fourth advance as a post-Pleistocene stage to be correlated with the Bühl advance in the Alps, chiefly on account of the high position of the snow line and the general weakness of the glaciation.

If we compare this scheme of events with our interpretation, we find, first, that the number of ice advances corresponds to our four glaciations. We also emphasize that the Karewa Lake formation ranges from an early interglacial into the second interglacial stage, though Dainelli considered so long a range as a possibility only. Also the first and second glaciations were, in his view, relatively larger than the succeeding ones, the second (or Riss glaciation) being of special magnitude. The origin of the Karewa Lake is placed by him in the first interglacial stage (or Mindel-Riss). This is where our newly collected data oblige us to depart from Dainelli's dating.

The lake-shore deposits of the Karewa formation must be assigned to an early Pleistocene time on account of the *Elephas* cf. *hysudricus* found at Sombur. This is a primitive elephant whose stratigraphic range is restricted to the Tatrot-Pinjor zones of the Upper Siwalik. Also, since these Lower Karewa beds lie between the first terminal moraine (Sind Valley) and the second glacial deposits, they must belong to the first interglacial stage. The lake-loess deposition of this stage corresponds to a similar silt accumulation in the plains as represented by the Pinjor zone. The folding of these beds in Kashmir was simultaneously recorded by the disturbance of the older Upper Siwalik beds, which are unconformably overlain by Boulder conglomerate. This conglomerate, merging into morainic outwash of the second glaciers, represents the great fan stage which Dainelli has assigned to his second glaciation. The 2,000 feet of fossiliferous Upper Siwalik beds underlying this zone indicate clearly a prolonged sedimentation which embraces the early Pleistocene. Hence, it is evident on paleontologic and stratigraphic grounds that the Lower Karewa beds are of an older Upper Siwalik age. They cannot, therefore, very well represent the Mindel-Riss interglacial stage (middle Pleistocene).

Moreover, the fauna of the Boulder conglomerate and of its equivalents in central India is of middle Pleistocene type, which argues against a later age, as do also the archeologic records (fig. 58). Also, it is not advisable to consider the fourth glaciation a postglacial advance, because its terminal moraines are succeeded by at least two smaller oscillations, reminiscent of the Bühl and Geschnitz stages in the Alps. This fourth advance was more in the nature of the Würm glaciation, for not only does the terrace record suggest this correlation, but the relative position of the fourth moraine is such as to reveal a strong and lasting glacial expansion followed by general and final retreat.

Although it should be realized that Dainelli himself did not strictly insist on such correlations, it is nevertheless, in the light of these observations, necessary to assign an older age to his Pleistocene stages. The great dividing line is the fan

or Boulder conglomerate stage, which separates lower and upper Pleistocene, and this corresponds to the maximum glaciation of the Pir Panjal. With this view in mind, it is possible to recognize the main events of the Kashmir Pleistocene in the upper Indus terrane.

THE PLEISTOCENE RECORDS IN LADAK OR INDIAN TIBET

Previously (1935, pp. 41–46) I have made an attempt to analyze the glacial history of the Kargil Basin (about 60 miles north-northeast from the upper Sind Valley). Its sediments show two stages of glaciofluvial nature, separated by an erosional disconformity. My former interpretation argued for two fill stages belonging to the second and third interglacial periods of Dainelli's scheme. The observations on the Kashmir gravel formations lead me now to believe that Dainelli and Trinkler were right in assigning them to a second and third expansion, for it is clearly the late glacial outwash of the respective moraines which built the major gravel beds in Kashmir. All of us agree that the second glaciation was more effective in the Kargil Basin than the third, as no moraines were found in the basin center. Also the fourth moraines are restricted to outlets of higher side valleys, a fact which reflects the lesser intensity of this glacial advance. The upper gravel, being associated with extensive laminated lacustrine silt, marks the time of a great lake formation, as Dainelli also observed. Indeed, these lake beds make a datum horizon all over the upper Indus tract that is easily recognized by the white or light-gray shell-bearing silt layers. The origin of these silts, as Dainelli has shown, is not connected with any violent changes in drainage due to uplift (as was the case with the Karewa lake beds), but with local ice barriers brought about by the damming effect of glacial waters through tributary glaciers. Such glacial dams occasionally still form in the valleys of the high Karakoram. The latest example of this was the Chong Kumdan glacier dam in 1932, as described by Mason (1933, pp. 98–102), which temporarily blocked the Shyok River. In view of the recency of earth upheavals in the Himalayan region, it is, of course, quite possible that such sudden advances of single tributary glaciers toward the main valley are due to ice catapulting promoted by seismic disturbances. Such catapulting may well have occurred during the third glaciation, but no proof can at present be offered. In any event it would appear that these glacial lakes were younger than the Karewa Lake of Kashmir. The source area of the lake silt was presumably the rock flour of ground moraines, but, in addition, we might suspect eolian transport, especially for the loesslike lake beds described by Trinkler and Norin from Lamajuru and the Indus Valley.

According to Trinkler (1932, p. 54) the Lamajuru lake loess is at least 450 feet thick, and its origin is unquestionably connected with the third glaciation. A young moraine is found 456 feet below the top surface of the lake beds, representing presumably the fourth advance.

White-gray lacustrine silt appears also at Skardu, the glacial records of which Dainelli has described in detail. Here, as at Kargil, the lake beds are associated with glaciofluvial outwash from the third moraines. An older moraine and boulder

gravel were observed some 1,500 feet above the present Indus bed, indicating the last glaciation of the main valley during the time of the second expansion.

Above Skardu, especially between Nurla and Leh, the Indus flows through thick gravel deposits. Trinkler distinguished an older cemented boulder gravel, or breccia, from younger loose sandy pebble beds with lacustrine silt. The breccia bears certain resemblances to recent solifluxion débris characteristic of the Tibetan plateau. To judge from Dainelli's and Trinkler's studies, it becomes evident that the older cemented gravels represent thick fan débris, redistributed by glaciofluvial action during a fill stage following on the heels of a major glaciation. Trinkler (1932, p. 57) rightly connected the two Indus gravels with two fill stages, separated by a long erosion period during which the river incised its bed by many hundred feet. As the younger gravels are not associated with glacial action in the valley proper, it must follow that they represent outwash from third glaciers. Hence the fan débris should belong to the second glaciation. The lake beds appear again in the later valley fill, and it can clearly be seen at the village of Pitok (or Spituk) that they rest against the huge fan which issues at Leh from the slope of the Ladak Range. The great Indus fans, so conspicuous to all travelers, have all the appearance of the Karewa gravel or the Boulder conglomerate fans. The fan at Leh, for instance, is 5 miles wide at its base and 6 miles long, and its thickness must exceed 1,000 feet. Such great accumulations of débris are difficult to explain unless their formation is connected with the glaciofluvial action at the end of the last great Indus glaciation. In addition we are inclined to attribute their origin partly to uplift of the Ladak Range. The dip slope of some of these fans is so steep as to suggest tilting in later time, which may well date back to the middle Pleistocene.

Quite clearly, then, the great Indus lake period followed the fan stage, and prolonged erosion separated these stages. Fortunately both cycles are well represented in the northwest Punjab, where the Boulder conglomerate is disconformably overlain by the Potwar loessic silt. The silt is not a real lake deposit but essentially a "pluvial loess," yet its origin falls into the time of the third glaciation, in analogy to the Indus lake silt. This cannot be mere coincidence, and we ask ourselves what agency could best account for the simultaneous deposition of thick silt on the corresponding flanks of the main Himalayan Range. Previously (De Terra and Teilhard, 1936) I have suggested that the Potwar loessic silt originated under peculiar climatic conditions imposed by the monsoon climate at a time of general refrigeration during the third glacial advance. Its governing conditions probably were turbulent atmospheric conditions and an unusual supply of silt held seasonally in aerial suspension and precipitated with the aid of heavy seasonal rains. Such a constellation of factors must, in somewhat varied form, also have operated in the mountainous tract; in fact, the Karewa sediments indicate clearly that such was the case, so far as the Kashmir Basin is concerned. Although in early and middle Pleistocene time the monsoon influence was here strongly felt, in view of the lower altitude of the fore ranges, it is obvious that their subsequent uplift should have checked the northward advance of the monsoon. However,

meteorologic observations show that nowadays the monsoon actually reaches the upper Indus terrane through its highest wind currents. It is also commonly observed by all travelers that western winds make for soil transportation in these high longitudinal valley tracts. Dust storms occur regularly in the upper Indus and in tributary valleys, giving rise to regular dune formations. Present conditions thus allow inference as to heavy eolian sedimentation in former times, when the process must have been greatly intensified, owing to the factors above mentioned. The principal valleys, having been ice-free during the third advance, were largely inundated, but silt was abundantly supplied from contemporaneous and older moraines. In addition, it is known that dust-falls of southern origin are frequently encountered in these areas. To such falls we may attribute a large share in the deposition of lake loess; in fact, its peculiar distribution within the leeward slopes of the high ranges is difficult to account for unless the eolian drift was brought about by southern or southwestern winds. The origin of the upper Indus lake silt therefore was due largely, first, to damming of glacial lakes by tributary glaciers; second, to eolian drift of southern origin by monsoon outliers which dropped their sedimentary load in "dead corners" beyond the high ranges; and third, to eolian drift by valley winds blowing from the west or southwest.

Dainelli has shown that lake formation of the third advance was not restricted to the Indus Valley but that it is equally well represented along certain secondary tributaries which drain longitudinal valley basins on the border of the Tibetan plateau. These are the basins of Tankse (12,800 feet), of Panggong (14,000 feet), and of Changchenmo (15,000 feet). All three are strike valleys of structural origin (Panggong and Changchenmo being bordered by fault lines) and all are, or were until recently, drained by tributaries of the Shyok River. The Panggong and Tankse basins were in Pleistocene time connected by a stream and formed thus a single river artery parallel to that of Changchenmo. At one time the Panggong and Tankse basins experienced heavy glaciation, as is evident from the trough shape of the major valley sections. As in the Indus Valley the trough bottom is filled with thick, in places cemented, ground moraine and boulder gravel, overlain by white lacustrine silt. To judge from this sequence and from the great thickness (400 feet) and coarse nature of the ground moraine encountered along the Tankse River, there can be no doubt that this glaciation belonged to either the first or more likely the second advance. Everywhere the lake beds rest on dissected older moraine or on the glaciofluvial outwash filling of the trough. The regional distribution of the lake beds in relation to the Shyok Valley elucidates their mode of origin.

In the Tankse and Changchenmo valleys there are no traces of younger moraines on top of the silt except for terminal moraines derived from tributary glaciers which lie at the outlets of high side valleys. This we take to indicate that the Tankse Valley proper was ice-free during the third glaciation. However, from Dainelli's observations it would appear that the Shyok Valley was occupied by a glacier which dammed the waters of the Tankse-Panggong and Changchenmo streams. The third Shyok Glacier, in other words, blocked these tributaries and gave rise

to widespread inundation of the plateau valleys. The fact that the surface level of the lake beds now lies some 300 feet above the Shyok River bed cannot disturb us, in view of the great thickness of the third Shyok Glacier as indicated by its trough remnant, which lies several hundred feet above the former lake level.

Fortunately we have another means by which we can check these interpretations. In the Tankse Valley I observed four terraces, which are sketched in figure 146. The topmost is cut into the thick ground-moraine filling, representing the older glaciation. T2 is underlain by lake silt, T3 is cut into the lake beds, and T4 is made of coarse gravel banked up against a prominent slope below T3. This arrangement resembles the terrace system of Kashmir; in fact, it is analogous if we remember that the lake beds here represent the third glaciation. It would also seem that the ground moraine and associated boulder débris belong to the second advance, in analogy to the stratigraphic terrace pattern in Kashmir. If so, the U-shaped slopes above T1 would belong to the trough of the second glacier.

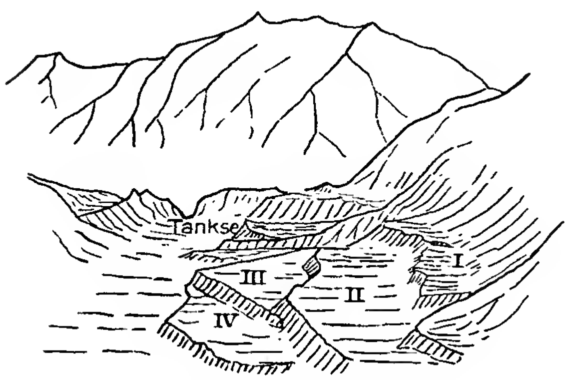


FIGURE 146.—Terraced valley at Tankse, in Ladak.

The Panggong Basin presents a very similar arrangement. Huntington (1906*b*), Dainelli (1922), and Trinkler (1932) described it as a broad flat-bottomed valley which was glaciated during an older ice advance. Indeed, its steep flanks exhibit the scouring effect of glacier ice almost 1,000 feet above the level of Panggong Lake. This glacier doubtless moved from southeast to northwest, following the gradient toward the Tankse Basin, where it coalesced with another glacier that occupied the valley on the corresponding slope of the Panggong Range.[1]

The southwest shore of Panggong Lake is built of a fluvio-lacustrine formation, which I had occasion to study at various localities. It is composed of two different deposits—a lower one consisting of cemented conglomerates and fan débris of varying thickness and an upper one of laminated fossiliferous silt and loose gravel. The silt is a lake deposit with plants, fresh-water shells, and fish remains. A recent pollen analysis by Deevey (1937) has shown that the flora was of temperate character and similar to the recent plant assemblage of this semiarid highland country. The invertebrate fauna also suggests that it was well established in the third glaciation. Bench lines, corresponding to high-water levels of this Pleistocene lake, lie 190 feet above the present lake and transgress the present watershed toward the Tankse Valley, thus indicating a lake extension in that direction. Notwithstanding the difference in altitude between these high Panggong bench lines and T2 near Tankse, it is safe to infer that the lake beds of both areas are homotaxial. Remnants of the same lake silt were observed in the intermediate valley near Truktagh, where they lie between coarse fluvial gravels. The difference in altitude

[1] For a detailed description of glacial features in the Panggong Basin see especially Dainelli (1922, pp. 365 ff.) and Trinkler (1932, pp. 4 ff.), also my map of that region (1934).

between T2 at Tankse (about 13,100 feet) and the highest bench line (14,190 feet) is of such magnitude as to suggest a tectonic displacement. Trinkler observed that the old lake beds of Panggong are tilted 5° toward the basin. Hedin, I, and others have presented a variety of evidence for young mountain uplifts all over the area.

The age of the old Panggong lake beds is of great interest, in view of the remote location which they hold in relation to the Indus Valley. The basal cemented gravel is to all appearance a glaciofluvial fill succeeding the great Panggong Glacier. Erosion followed, and then deposition of lake beds with another set of fluvial gravels on top. In these upper beds were found between Man and Spangmik: *Valvata piscinalis* (O. F. Müller), *Lymnaea lagotis* f. *solidissima* Kobelt, *Gyraulus ladakensis* Neville, and *Pisidium stoliczkanum* Prashad, all of which are still living in the region. At Yaktil the same shells were found in addition to *Gyraulus pankongensis*. Formerly I was inclined to consider this lake formation, like that of the Kargil Basin, as being of second interglacial age. This opinion was based on

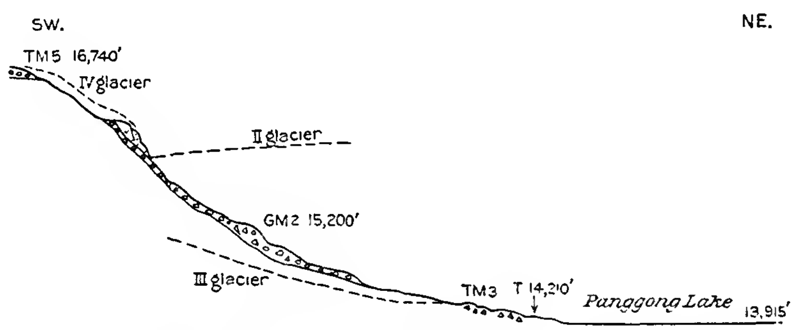


FIGURE 147.—Glacial slope profile in Panggong Basin. TM5, TM3, terminal moraines; GM2, ground moraine.

Trinkler's observation that the lake beds are overlain by moraines. A reexamination of the section near Yaktil, however, disclosed the fact that the silt is here covered by landslide deposits of more recent date. Huntington (1906*b*, p. 614) has described an interesting succession of three moraines near Man. I studied this section in 1932 and agree with his interpretation.

Here lake beds rest against a moraine "belonging to the first glacial epoch after the retreat of the ice from the main Panggong Basin." This can only have been our third advance, when tributary glaciers descended toward the lake, forming moraines against which the lacustrine silt was deposited. Later glaciations left two moraines, 1,000 to 3,000 feet above the third terminal moraine, indicating a fourth and an early postglacial advance. Huntington himself correlated the third moraine with his 200-foot lake bench (our 190-foot bench), which was dissected during the last interglacial epoch. He correlated a lower, 60-foot bench with the fourth moraine and considered the lake silt as synchronous with the last major advance. In view, however, of the erosional disconformity between the lake silt and the upper gravels, it is more convincing to assign the gravels to the last glaciation. This, then, enables us to visualize the synchronization of the Panggong history with that of the upper Indus and Kashmir terranes, for we can recognize

the same stages, beginning with the second glaciation and ending with the post-glacial advance (fig. 147).

The Changchenmo Valley marks the westernmost boundary of the Shyok drainage toward the Tibetan plateau. It is at a high altitude and lies in a region characterized by scant rainfall and long, severe winters. Its upper portion is part of the mature plateau relief, which was generally unfavorable for the formation of large valley glaciers. (See De Terra, 1934.) This may account for the absence of any traces of younger glaciations. A few erratics were encountered near Tsok Tsoler, indicating that one of the older advances developed a glacier in the valley proper. This is substantiated by the presence of ice-contact deposits about 5 miles downstream from Kyam, which make an old gravel fill some 200 feet thick. Lake silt and younger gravel repeat the Pleistocene sequence so well known from previous descriptions. Four terraces were recognized by me in 1932, the highest of which is cut into the older boulder gravel. The presence of this system of Pleistocene river levels in this remote corner of northern India testifies to the regional extension of the various stages throughout the upper Indus terrane (fig. 147).

Correlation of glacial sequences in upper Indus terrane

Period	Kargil	Indus Valley at Skardu	Indus Valley near Leh (10,000 feet)	Panggong Basin (14,000 feet)	Changchenmo Basin (15,000 feet)
Postglacial..			Upper moraines in side valleys above 15,000 feet.	Fifth moraine of Man. Landslide deposits.	No glaciation.
IV....	Terminal moraines in side valleys, 3,100 feet.	Terminal moraines 500–1,000 feet above basin floor.	Younger terminal moraines and fans.	Fourth moraine of Man. Upper gravels and sands, 60-foot Man lake bench.	No glaciation. Lower terrace and gravels, fans. Fourth terrace.
IV–III.	Erosion....	....	Erosion . . .	Erosion	....
III....	White lake silt, Boulder sand } 380 feet.	Lake silt and gravel. Terminal moraine of side glacier damming the main valley.	Lake silt at Lamajuru, 450 feet. Second fan stage, loose gravelly sand.	Third moraine of Man lake silt and 190-foot lake bench.	No glaciation in valley; lake silt. Second terrace.
III–II.	Erosion	. . ..	Erosion.	Erosion	Erosion . .. .
II.....	Boulder gravel, ground moraine at 269 ft. } 486 feet.	Thick boulder gravel, moraines 1,200–1,500 feet above Indus bed. Largest glaciation.	First fan stage, thick fan débris (partly solifluxion deposits) filling old glacial trough, +1,000 feet cemented breccias and gravels.	Ground moraine and glaciofluvial cemented gravels. Panggong Glacier.	Boulder gravel, ice-contact deposits, and redeposited solifluxion débris, 200 feet.
II–I ..	Erosion				
I	High remnants of glacial troughs.				

G. SUMMARY OF THE PLEISTOCENE IN KASHMIR

In the two previous sections it was shown how the various stages of the Kashmir Quaternary were simultaneously recorded in the drainage areas of the Indus, Jhelum, and Chenab rivers. Frequent reference was made to certain

geologic events which characterized particular periods, such as the formation of boulder fans or the deposition of lake beds. Notwithstanding the facts that sedimentation varied according to local conditions and that the records of glacial advances differ somewhat in various regions, it is nevertheless obvious that the Pleistocene history of the area is marked by definite cycles. Detailed descriptions have shown that these cycles were determined primarily by structural and climatic factors, and this dualistic character gives us a choice as to how to arrange the various stages in the most plausible chronologic manner. Either we can divide the Pleistocene of Kashmir into glacial and interglacial stages, or we can follow a more general scheme by recognizing lower-, middle-, and upper-Pleistocene divi-

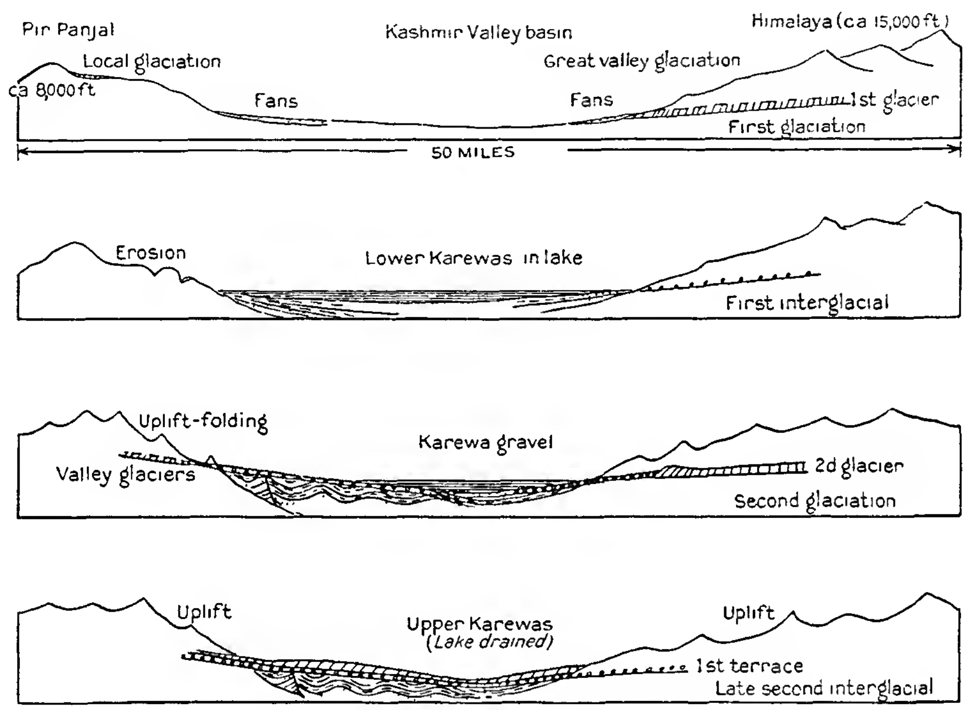


FIGURE 148.—Schematic cross sections through Kashmir Basin during the early and middle Pleistocene.

sions. The former procedure would obviously not emphasize sufficiently the structural or erosional breaks in the sequences. Also it would be difficult, if not wholly misleading, to designate certain strata in nonglaciated regions with names given to true glacial deposits. Moreover, in a purely glaciologic scheme the various zones would transgress certain paleontologic groups, which are of great importance in view of the pending correlation with the great Siwalik series of India. For these reasons we prefer to use the more generally employed threefold division.

This permits us at once to recognize a lower Pleistocene subdivision embracing the first glacial and interglacial stages, separated from the middle Pleistocene by an angular unconformity or an erosional break. Gravel fans and lacustrine-fluvial silt are its main sediments, which are folded. Its two stages are clearly represented in the Siwalik series, where they are known as the Tatrot and Pinjor

zones. Faunistically, both complexes are linked by a primitive elephant, which appeared in the plains as a prominent member of that faunal assemblage which is known as Upper Siwalik. This is, as Teilhard de Chardin (1937, p. 162) has recently suggested, related to the Villafranchian of Europe. Its association with early Pleistocene glacial records in India tends to strengthen the conception of certain paleontologists (Haug, Hopwood, and others) who assigned this fauna to a post-Pliocene age.

The middle Pleistocene would embrace the second major glaciation and the following long interglacial stage, divided from the upper Pleistocene by another unconformity. It is characterized by the formation of boulder fans and thick glaciofluvial deposits, greatly dissected by subsequent erosion (fig. 148). The absence or insufficiency of fossil records is somewhat counterbalanced by the presence of a pre-Soan (Cromerian) type of flake culture in the foothills of the northwest Punjab, traces of which appear also in a rolled condition in the lower Narbada zone of central India in association with a straight-tusked elephant. (See part II of this volume.) There is good reason for restricting the middle division of the Pleistocene to these two stages—first, because the glaciation was very effective and sedimentation excessive (amounting to 2,000 feet in the foothills), and second, the succeeding erosion was of such magnitude as to suggest a prolonged interval which, in the Kashmir Valley, comprises not less than two substages (Upper Karewas and formation of upper terrace). In Europe also the second interglacial period was very long; in fact, it is thought to have occupied almost one-third of the entire Pleistocene (Penck and Brückner, 1909).

The upper Pleistocene comprises the last two glaciations and an interglacial stage. Its separation from the postglacial or Holocene epoch is made possible by records that permit us to distinguish a general and final retreat of mountain glaciers and an ultimate lifting of the snow line to its present position. Also, the terrace formation reflects a distinct break following the aggradational stage of the fourth terrace, which is the last major gravel accumulation in the mountainous tract. Tilting of terraces and lacustrine beds indicates that the general uplift of the region continued during this time, though probably with lesser intensity than in previous periods. Outstanding characteristics are the formation of three terraces (T2-T4) and of loessic lake beds in the northern upper Indus terrane, also the continued uplift of the entire Himalayan tract.

Altogether, the Pleistocene history of Kashmir displays so puzzling a variety of geologic events that one is compelled to seek an analysis of the principal factors. These could conveniently be grouped into two major processes—a diastrophic and a climatic cycle. However, the description of the Pir Panjal glaciation has shown how closely these processes influenced each other, as exemplified by the uplift of the monsoon barrier in its effect upon drainage, sedimentation, and glacial movements. Indeed, the interplay of geologic and climatic forces was so constant and thorough that it is impossible to segregate the various processes and consider each separately. Hence it would seem that a more detailed historic account of each stage will do greater justice to the peculiarities of the region. Also it will help to

emphasize the respective rôle of each process, and this will lead to more vivid appreciation of the most important events. In doing this we are fully aware of the incomplete status of our information as regards both certain regions in Kashmir and the origin of the Ice Age in general, and no attempt will be made to add a new hypothesis to the existing host of theories. Yet we must be emphatic on one particular feature—namely, the dependence of Pleistocene glaciation on the diastrophic character of a mobile mountain belt. This relationship, we feel, has not been sufficiently recognized in other glaciated regions, such as Central Asia and the Alps, where similar if not identical conditions are found.

EARLY PLEISTOCENE

First Glaciation

The scenery which this region presented at the beginning of the Pleistocene must have differed greatly from that of our time. To begin with, the Kashmir Valley was less elevated, and its southern rampart, the Pir Panjal, lacked that alpine grandeur that enchants the traveler today. That it was mountainous is made evident by sporadic traces of an earliest glaciation found on the highest slopes of the watershed (fig. 148). Plateau remnants and planed surfaces show that its relief had been in a stage of advanced maturity ever since Pliocene time, as is also recorded by the fine-grained nature of the Middle Siwalik beds, which represent detritus washed down from the southern Himalayan Mountains. Yet the appearance of conglomerates in the Dhok Pathan zone and even more the existence of ancient rock benches and composite slopes clearly testify to one or more rejuvenating effects of an early mountain uplift upon the drainage of the entire northwestern Himalaya prior to the first glaciation. In this is revealed the tendency of intermittent growth from the Tertiary period onward. This diastrophism was and presumably still is determined by thrust faulting between various formational groups which tend to move both horizontally and vertically, resulting in a southward displacement of older rocks upon foreland sediments, accompanied by uplift of the mobile belt. The Kashmir Valley was at that time a faulted intermontane basin, bordered on the north by the main Himalaya, which was highly elevated, as the intensity of the first glaciation proves. This was probably promoted by a northward advance of monsoon currents due to the lesser altitude of the southern barrier. The Sind and Liddar valleys bore glaciers that terminated at the respective valley outlets and spread coarse outwash aprons into the valley (fig. 148). The lower limits of glaciation on the corresponding valley flanks are unknown, but it is evident from the distribution of the first moraines that their altitude was small, because the Pir Panjal had not yet been elevated. In fact, if we reduce its height by, say, 6,000 feet (the approximate amount of uplift as deduced from the difference in altitude at which Lower Karewa plant beds are found), it appears that the first moraines were deposited in the Pir Panjal at a level similar to that on the Himalayan side.

Formation of fans and river gravels was already under way when this ice advance began. Thick accumulations of débris underlie the Lower Karewa lake

beds and in the foothills rivers deposited what is now recognized as the Tatrot zone. (See tabulated summary facing this page.) It would seem as if this oldest débris was released by uplift and rejuvenation of antecedent streams.

The climate of this stage should have been temperate but somewhat colder than the present. The fossil records of the homotaxial Tatrot zone proper suggest that the assemblage of mammals was greatly impoverished in comparison with that of previous Siwalik times, poorer also than that of the succeeding Pinjor zone. Colbert (1935) listed 11 species as compared with 89 from the Pinjor and 102 from the preceding Dhok Pathan zone. Such a discrepancy may be due in part to conditions unfavorable for the preservation of mammal remains, but on the other hand it must be remembered that the richest bone beds in the Siwalik series of India are more often found in the coarse wash products than in fine-grained sediments. Had there been a very great wealth of mammals in Tatrot time their remains would surely have been preserved somewhere. Also the fauna is composed of such types as elephants, pigs, and bovids, which are more easily adapted to climatic changes than the Rhinocerotidae or anthropoid apes. The latter are missing altogether, for the only type listed by Colbert (*Ramapithecus*) was of uncertain location and appears to be derived from the Dhok Pathan zone. As for *Hippopotamus*, which generally is a climatically specialized type, it would seem that most of its fossil remains are derived from Pinjor beds rather than from basal Pleistocene strata. Suffice it to say that the Tatrot fauna proper indicates a less favorable habitat for land mammals as testified by the numerical decrease and the selected type of fauna. This, we believe, reflects the impact of the glacial climate on the rich mammal faunas of the Siwaliks.

First Interglacial Stage

The accumulated effect of the early fan formations, the uplift of the Pir Panjal, and the dissipation of the first Himalayan glaciers led to damming of the upper Jhelum in the Kashmir Valley. On both flanks of the basin tilted fans underlie the silt and clay of the Lower Karewa beds. The newly formed lake had its outlet near Baramula, but it was unable to overflow, probably owing to the great height of the barrier, which may have gained in altitude as the Kashmir Basin floor subsided. The intermittent supply of coarse sand into the otherwise silty lake beds at least indicates that the uplifting tendencies had not come to a stop. The supply of glacial rock flour from moraines, the eolian drift from the alluvial plains of the south, and, finally, chemical precipitates contributed in building up a thick column of lacustrine beds. This stage of heavy lake sedimentation corresponds well to a phase of great silt accumulation in the adjoining plains, where the Pinjor zone reaches a thickness of several thousand feet. Thus both intermontane and foreland basin received, simultaneously, a vast load of fine sediment, comparable in magnitude to the red-loam fans of North China.[1] And here, as in China, we are inclined to interpret this sedimentation as having been induced by a sinking tendency of the basins, subsequent to and partly contemporaneous

[1] See Teilhard de Chardin, 1937.

Summary of Pleistocene events in Kashmir Valley and adjacent regions

Period	Himalayan slope		Northern slope of Pir Panjal			Southern slope of Pir Panjal			Upper Indus terrane in northern Kashmir	Siwalik foothills and plains in northwest Punjab, Poonch, and Jammu
	Sind Valley	Liddar Valley	Rimbiara and Vishav valleys	Sokhnagh Valley	Ferozepur-Gulmarg	Middle Jhelum Valley	Poonch Valley	Chenab and Tawi valleys		
Fourth glaciation.	Terminal moraines 1–3, Sonamarg, 8,500 feet. Terminal moraines 4, 8,850 feet. T4 in lower valley, 50–60 feet. Aggradation in upper valley, 100 feet.	Terminal moraines 1–2, Burzulkut, 11,000 feet. T4, 30 feet. Aggradation.	Terminal moraines, 8,800, 8,760 feet. T4, 30–40 feet. Aggradation. Loess-loam on loose gravel.	Terminal moraines, 9,350 feet. T4, 40 feet. Aggradation. Loess-loam on boulder gravel.	Terminal moraines, 9,000 feet. T4, 30 feet. Aggradation. Loess-loam on gravel.	Glaciers in tributary valleys only. T4, 80 feet. Strong aggradation. Loess-loam.	Terminal moraines 1–2, 11,100 and 11,500 feet. Aggradation. T4, upper valley, 100–200 feet boulder gravel; lower valley, gravel and loam 30 feet.	T4, 60 feet. Aggradation. Loess-loam on gravel.	Terminal moraines 4. Glaciers in tributary valleys only. T4, loose gravel.	T4. Pink loam, silt, and gravel. Reddish loam.
Third interglacial stage.	Erosion and slight tilting. T3 buried under gravel of T4 in lower valley. Terrace in upper valley, 250 feet.	Erosion and slight tilting. T3 missing in upper valley.	Erosion and tilting of T3, 120 feet. Degradation. Thin loam cover.	Erosion. T3, 140 feet. Degradation. Loam cover, 10 feet.	Erosion and tilting of T3, 90–100 feet. Degradation. Thin loam cover.	Erosion. T3, 140 feet. Degradation. Loam veneer.	Warping, erosion. T3, upper valley 120–400 feet erosion; lower valley 70 feet aggradation (gravel and loam).	Erosion and tilting. T3, 250 feet. Degradation. Pink-loam cover.	Erosion and uplift. T3. Degradation.	T3. Degradation. (Soan industry)
Third glaciation.	Terminal moraines 1–4, 6,800–7,700 feet. T2, 100 feet. Aggradation. Gravel.	Terminal moraines, 8,100, 8,900, and 9,100 feet. T2, 70 feet. Aggradation.	Terminal moraines, 7,810–7,300 feet. T2, 265 feet. Aggradation. Boulder gravel.	Terminal moraines 1–2, 6,800–7,200 feet. T2, 210 feet. Aggradation. Boulder gravel.	Terminal moraines, 7,400; terminal moraines 1–3 in Ningle Valley, 6,100–6,500 feet. T2, 170 feet. Aggradation. Boulder gravel.	Glaciers in tributary valleys. Terminal moraines at 7,400 feet. T2, 210 feet. Aggradation. Fans, boulder gravel.	Terminal moraines 1, 4,500 feet; 2, 4,900 feet; 3, 5,200 feet; 4, 6,000 feet. Aggradation: boulder gravel, loessic silt. T2, upper valley 250–500 feet; lower valley 140+ feet.	T2, 350 feet. Boulder gravel and loessic silt.	Terminal moraines 3, local glaciation of Indus Valley. T2, younger valley fill, boulder gravel; lake silt locally 450 feet.	T2. Potwar loessic silt, ±350 feet. (Soan industry)
Second interglacial stage.	Prolonged erosion, tilting continued. T1, 150–200 feet. Upper Karewas in valley outlets.	Prolonged erosion, tilting continued. T1, 100–130 feet. Upper Karewas in valley outlets.	Erosion. T1, 420 feet. Degradation. Erosion. Upper Karewas, ±200 feet: topmost beds of eolian and fluvial origin; lower beds lacustrine; also fluvial outwash (partly varved).	T1, 300 feet. Degradation. Erosion.	T1, 310 feet. Degradation. Erosion.	Erosion. T1, ±300 feet. Degradation. Erosion.	Erosion. T1, upper tract 2,000 feet; lower tract 500 feet. Tilting and folding.	Erosion. T1, 500 feet. Degradation.	T1. Degradation Erosion.	T1. Upper terrace gravel. (Chelleo-Acheulian and Early Soan cultures.)
Second glaciation.	Tilting. Karewa gravel. Terminal moraines missing. Moraine, Mangom, 5,500 feet.	Tilting. Karewa gravel. Terminal moraines, Lioru, 6,600 feet.	Karewa gravel, ±400 feet: glaciofluvial outwash fans of brown patination. Lowest position of moraines on Karewa lake shore: Moraines above 8,000 feet.	Moraines ?, 7,700 feet.	Moraines ?, 7,600 feet.	Thick boulder fans, ±1,000 feet. Ground moraines at 5,300–4,500 feet.	Boulder conglomerate. Morainic débris (2,000 feet above valley floors at 7,000 feet).	Boulder gravel and thick fans.	Ancient valley fill. Boulder gravel. Great Indus Glacier.	Erosion, tilting. **Boulder conglomerate zone** ±2,000 feet. Boulder gravels in fan formation (oldest flake industry).
First interglacial stage.	Erosion, tilting. Lower Karewa lake beds. Thallophytic remains.	Erosion, tilting. Lower Karewa lake beds.	Folding and uplift. Lower Karewas, ±2,000 feet: Lake beds with fluvial inwash and eolian drift. Temperate flora. *Elephas* cf. *hysudricus*, *Cervus* sp., and fossil fishes (Schizothoracinae), mollusks, gastropods.			Strong erosion.	Folding; uplift and erosion. Pinjor zone, pink sand, silt, and clay.		Erosion.	**Pinjor zone**, ±2,500 feet. Pink silt and sand. Early Pleistocene fauna of Upper Siwaliks.
First glaciation.	As outwash. Malshahibagh conglomerate. Terminal moraines, Mangom, 5,500 feet.	? Terminal moraines, 6,100 feet, eroded.	Sporadic moraines only. Thick gravel fans, ±900 feet.		Sporadic moraines on highest slope of watershed.		Truncated glacial slopes with morainic débris (?) on highest parts of watershed. ?Tatrot gravel with far-traveled boulders.		Dissected trough valleys.	**Tatrot zone** conglomerate and sand. Upper Siwalik fauna.

with anticlinal uplifts of the flanking ranges. Changes of lake level are revealed on the Himalayan flank of the Kashmir Valley. To judge from the relative thinness of the Upper Karewa beds and from the scarcity of lake beds attributed to the second glaciation, it would seem that the maximum inundation of the Kashmir Valley took place in this interglacial epoch.

This is proved also by the existence of estuarine and lake-bay deposits in certain Pir Panjal valleys that subsequently became elevated to great height. It is in them that we encounter the plant- and lignite-bearing beds. On the corresponding flank a fossiliferous shore deposit yielded the remains of extinct mammals and fishes.

The climate unquestionably was milder than in the previous period—in fact, it must have been similar to that of recent times. The Lower Karewa plant assemblage affords a glimpse into the ecologic status of the Pir Panjal forests. The pine-oak forest, now restricted to the monsoon slope of this range, then extended north of its watershed. From this we may safely infer that the summers were warmer and more humid in the lower tracts than they are now. Elephants of Upper Siwalik type, deer, other artiodactyl mammals, and birds inhabited lake shores and valleys. They came from the southern plains, which once more teemed with mammal life. For most of the so-called Upper Siwalik fossils, numbering almost 100 species of mammals, were collected from the reddish silts and sands of the Pinjor zone beneath the Boulder conglomerate. Cercopithecoid monkeys then, as now, inhabited the foothills, but they moved in the company of large cats, elephants, true horses, pigs, and hippopotami. This Pinjor fauna is like a final flicker of Siwalik life after millions of years of exuberant growth. The habitat was more favorable than in Tatrot time, the normal temperature was presumably somewhat in excess of ours, and the country was less arid, as the great variety of fossil artiodactyl mammals, especially ruminants, indicates.

At the end of this stage diastrophism manifested itself more strongly than in previous Pleistocene time. The geanticlines of the Pir Panjal and the main Himalaya suffered sharp uplift, in consequence of which the Kashmir lake beds were compressed and dragged upward on the slope of the most mobile range. The strain exerted upon the older and more consolidated rocks led to faulting, which presumably followed the structural pattern previously established. The northeastward dip of the major fault at Udhampur, which tilted the Upper Siwalik beds, suggests that uplift was accompanied by a southwestward shifting of the Pir Panjal block toward the foreland of northwestern India. Rejuvenation of stream erosion thus was in full development when the second glaciation set in.

MIDDLE PLEISTOCENE

Second Glaciation

The uplift of the southern range was apparently of such magnitude as to cause here a more effective glaciation. The monsoon rains precipitated more heavily over the higher Pir Panjal, and lower temperatures brought about the

first extensive valley glaciation (fig. 149). On the Himalayan slope glaciation was also strong, though perhaps less severe than in the early Pleistocene stage, when rainfall must have been more abundant. In both regions glaciation checked, so to speak, the erosional effects of the uplift, and the glaciers carried much rock débris, which normally would have been swiftly transported to the basin or plains. In addition, the glaciers themselves provided morainic material. Hence, when the ice began to dissipate and retreat, huge quantities of débris were stored up, which the stream began to accumulate at the valley outlets. The newly freed stream channels once more resumed their activities, which must have been greatly promoted by the existence of a newly dissected and glacially scoured relief. As a result of this, large boulder fans were formed which came to rest upon tilted early Pleistocene beds. In the Poonch Basin they are represented by the Boulder conglomerate of late Upper Siwalik time. The difference in thickness between these two homotaxial zones is presumably due to two factors. First, the foothills unquestionably received fan detritus, throughout the second glaciation, from more powerful glaciers than either the northern Pir Panjal or Himalayan slope could have offered at a later time. Second, the stream gradients were steeper on the

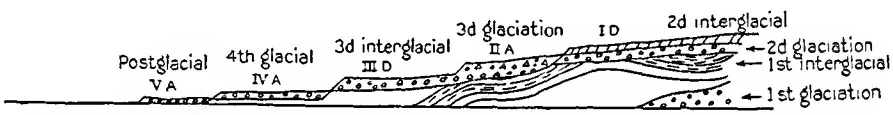


FIGURE 149.—Generalized terrace section in Kashmir. V A, IV A, II A, III D, I D, indicate aggradational (A) and degradational (D) stages.

plainward slope, because the effect of uplift should have been felt more here than in the northern tract. Moreover, it is probable that the foothills and plains received, at that time, more rainfall than the northern tract, and this would also have contributed to the rapid accumulation of gravel. These fans, therefore, are the geologic precipitate of both tectonic and climatic processes. The climate must have been distinctly unfavorable for mammals, because there are no known distinct records of the Siwalik fauna from the Boulder conglomerate zone. A few rolled bones of bovids and *Proboscidens* are all that are discernible in this deposit. Not even the sandy strata yielded fossil remains. This sudden lack of fossils would indicate the extinction of the Siwalik fauna during the second glaciation.[1] A great change of habitat took place. The climate grew colder and more stormy and, as streams spread their gravel load across the plains, the ground grew more barren. Rainfall, undoubtedly, was then in excess of what it is today. This is indicated by the deep ocher staining of the gravels, a type of patination wholly unknown in later deposits. It was evidently acquired at the time of deposition, for the gravels are patinated throughout, the implements included. Also, the sand or silt beds associated with the Karewa gravel are deeply stained, suggestive of abundant and intermittent rainfall.

[1] By extinction is meant both dying out of forms and migration to other regions, such as central India, where remnants of the Upper Siwalik fauna survived.

Under such climatic conditions one would expect to find records of loess deposition, yet there are few that we could attribute to this glaciation. The lower silt beds of the Upper Karewas are derived in part from wind drift and were probably laid down under glacial conditions, and a good percentage of the silt admixture in the gravel fans might well represent dust precipitates. But such records compare unfavorably with the thick silt accumulations of previous and succeeding stages; in fact, one might well say that the scarcity of loessic beds in this stage is the exception that proves the rule. For dust precipitation has occurred in varying degrees throughout the Quaternary period, continuing even to recent times. Apart from the possibility that loess of this stage did not come under observation, it is equally possible to attribute its absence to the great period of erosion which succeeded the second ice advance.

Second Interglacial Stage

In the Kashmir Valley lake, deposition continued for some time but was ultimately followed by eolian drift after the lake had drained off to the plains. We do not visualize this drainage of the Karewa Lake as a catastrophic event, chiefly because the lower set of beach lines indicates a gradual lowering of the water table. The melting of the second glaciers still fell largely into the second glaciation and contributed, undoubtedly, to the formation of fans and older gravel fill, but at the same time snow waters should have been stored in the valley, as still happens on a smaller scale after heavy rainfalls in the mountains. It is this temporary inundation which was chiefly recorded in the Upper Karewa beds. With the general decrease of water supply and the Jhelum River actively engaged in deepening its bed in the boulder gravels of the previous period, the lake was largely drained off, and seasonal dust storms deposited a veneer of yellow loessic silt over the shell-bearing lake beds. This process was checked by erosion, which must have gained full force as soon as the major valleys were freed from ice. Except for the 200 feet of Upper Karewa beds no other deposits are known to us from this stage. Rivers entrenched themselves into the glacial and fluvioglacial débris and may have denuded whatever was previously deposited. Ultimately, vertical erosion gave way to lateral stream cutting, from which resulted the first terrace.

But this relative stability of stream power was temporary, as is indicated by the renewed excavation which resulted in the prominent slope between the two upper terraces. In the Kashmir Valley, as well as in the foothills, streams cut 150 to 155 feet into the boulder gravel, so that at the end of this stage newly incised channels were provided for the following glaciers and glacier streams.

This erosion was due primarily to continued uplift, which is documented by the tilting and even faulting of fans, as on the plains near Chaomukh and Jammu. At the very beginning stream erosion must have been accelerated by the water supply from melting ice. But once the drier climate had established its reign, the cutting power would have been greatly reduced if upward movements had not caused continued entrenchment. Hence, it seems that the uplift continued in force, with slight interruptions or variations, ever since the first interglacial stage.

Except for the fact that this stage was one of prolonged deglaciation and erosion, there are no other geologic ways by which we could reconstruct climatic conditions. Only the archeologic records prove that early paleolithic man inhabited the adjoining plains, and this fact shows that at least a favorable habitat existed for man, who, at this cultural stage, was dependent on big game. The abundance of paleolithic sites attributed to this interglacial stage, as described in the second part of this memoir, and above all the magnitude of river action argue for a very long "dry" interval. Erosion and the weathering processes of a climate of drier type unquestionably account for the lack of fossil records.

Third Glaciation

Through the newly deepened stream channels glaciers advanced afresh. Their movements were more variable than those during the second glaciation, owing partly to successive periods of ice stagnation during the retreat stage and partly to a steepening of valley gradients on the Pir Panjal slope. The terminal moraines of this stage display, normally, three or four distinct boulder ridges varying from each other in altitude by 1,500 feet. Their fresh state of preservation, however, distinguishes them clearly from older glacial deposits. The glacial troughs are only half or even one-third the size of those of the previous glaciers. This general decrease in glacier formation is strikingly revealed by the absence of any continuous Indus and Jhelum glaciers. In fact, the glacial records indicate that the main valleys were ice-free or only locally occupied by lakes of tributary valley glaciers, which led to the damming of snow waters and lake formation in the upper Indus terrane.

On the northern Pir Panjal slope glaciers advanced a few miles through valleys previously cut into the Karewa lake beds. Despite the uniform decrease of glaciation, these ice tongues reached low altitudes wherever they followed steep valley gradients, presumably formed during preceding uplifts. Glaciation overtook an accelerated stream erosion, thus causing an abnormally strong momentum of ice flow on the southwestern slope, where the Poonch Glacier advanced to 4,500 feet. The differences in the position of the third moraines on the respective valley flanks can in each valley be attributed to a steepening of the thalweg due to previous uplift of the area. Hence, it may be said that the crustal mobility of the basin flanks locally determined the extension of glaciers. Quite possibly a similar process determines present-day individual advances of certain glaciers in the neighboring high Karakoram, especially on the Nubra-Shyok watershed, known for its rapid glacier movements.

Simultaneously with this glaciation there occurred extensive inundations in the upper Indus region, which brought about thick accumulations of lacustrine silt derived from glacial débris and eolian drift. The eolian material is prominent in the sub-Himalayan foothills of Poonch and Punjab, where it covers the terrace gravels of the younger fan period. These terrace gravels mark a distinct fill stage, which succeeded the relief making of the second interglacial period. In upper Poonch and Kashmir the gravel of the second terrace can be traced to the third

moraines, from which it derived its load of boulders and glacially shaped débris. In the mountains brown silt was spread over this second terrace, which is presumably of fluvio-eolian origin and homotaxial with the loessic lake beds in Ladak and the Potwar silt of the Punjab (fig. 150).

The position of the second terrace above the present stream beds varies greatly. This is not surprising in view of the varying degrees of the initial stream power and of subsequent erosion. Differential uplift is unquestionably the cause of the high position of the second terrace in the southern slope valleys as compared with the lesser altitude on the northern terrane. It must also be remembered that preglacial and early Pleistocene uplifts, as well as glacial scooping, may have caused nicks in the longitudinal valley profiles, which should have led to irregularities in the initial position of ancient stream levels. Tilting has produced the

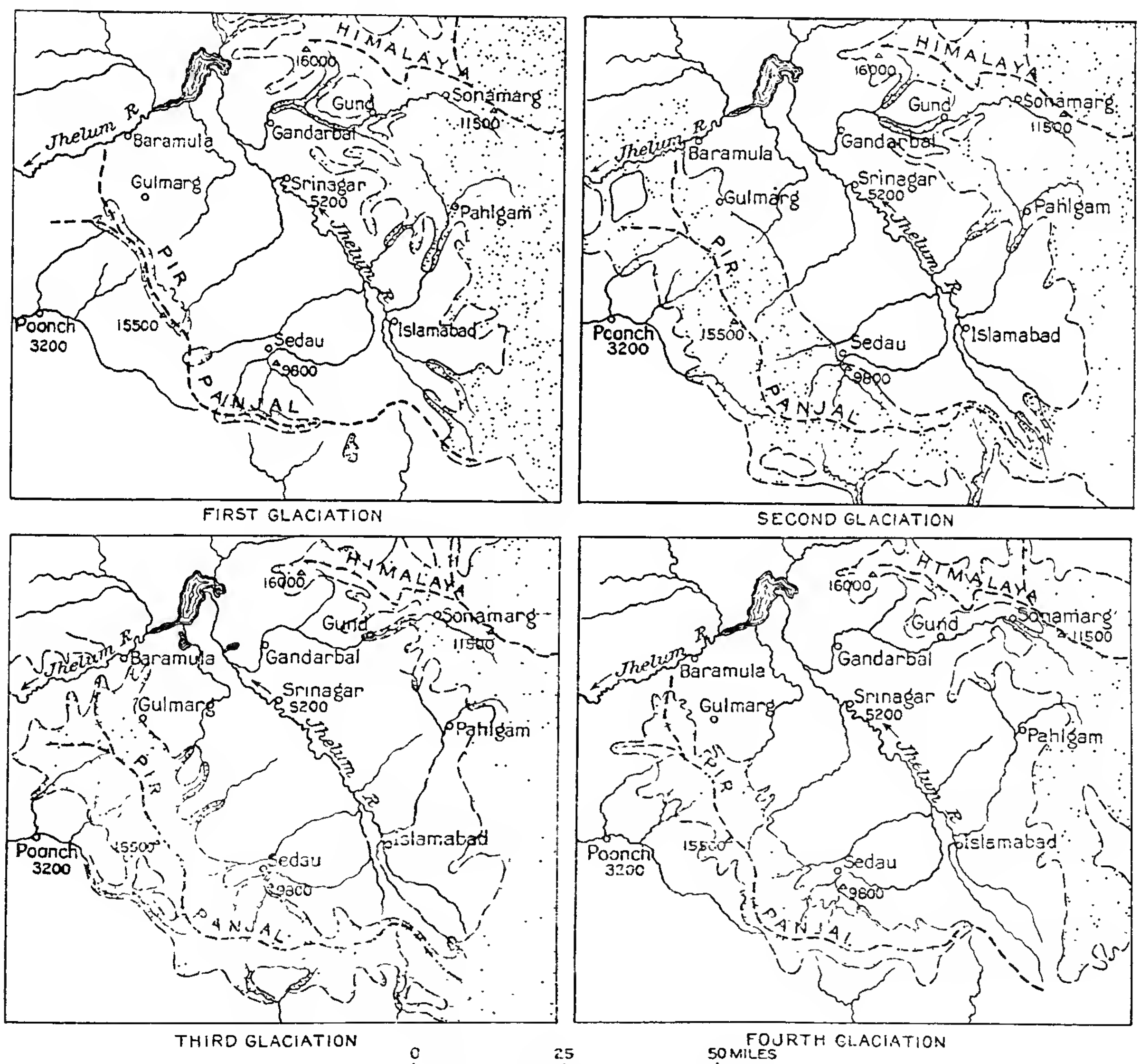


FIGURE 150.—Proportionate magnitude of four glaciations in Kashmir. Stippled area, glaciated and snow-bound terrane.

great differences in level within a single valley tract—for example, the Poonch Valley—a feature also characteristic of the younger terraces.

From the variety of fresh-water mollusks found in the lake beds of this stage, it would seem that the fresh-water fauna in the mountainous tract was somewhat richer than it is now. The pollen content of the lacustrine silts at the shore of Lake Panggong would indicate that the region was forested in parts. Also, vegetation must have been more abundant in the plains, for paleolithic man would hardly have left so abundant records of his manual skill unless hunting gave him the initiative for the manufacture of tools and weapons whereby he secured his maintenance. More will be said about the climatic characteristics of this stage in the second part of this memoir.

Third Interglacial Stage

The retreat of the glaciers set free once more the forces of stream erosion, which had previously been checked in the more highly elevated regions by glaciation. As a consequence rivers lowered their channels, and lakes emptied through deepened spillways. In some cases vertical erosion amounted to 150 feet, but again the final level of T3 is found in greatly varying positions. The third terrace generally marks the second occurrence of degradation in this region, but upon approaching the plains tract, signs of simultaneous filling due to deposition of the sedimentary load near valley outlets are encountered. In the Poonch Valley, for instance, T3 changes in the lower tract from a degradational to an aggradational terrace. Here, as well as in other valleys, brown loam and gravel cover the third terrace, indicating that the forces of fluvio-eolian drift were still active as in previous times. There is, however, a notable lack of eolian deposits, as compared with the thick accumulations of loessic silt that characterized the preceding glacial stage.

Presumably mountain uplift continued, though there are no sure signs by which to judge its intensity. The slope beneath the second terrace rather reflects rejuvenation, proceeding at normal speed until the rivers became graded on the levels of the third terrace.

The great width of T3 indicates that lateral erosion remained stationary for a long time, and as the rivers were able to cut a wide terrace, even in the unstable foothills, one can infer that this was a time of comparative tectonic calm. However, at the end of this stage violent erosion set in, T3 was tilted, and the loess sheets in the foreland were warped. Rejuvenation proceeded at great speed, as the prominent slope beneath T3 indicates, and so general and deep was the dissection that the waters of the fourth glaciers did not succeed in completely filling the new channels with their gravel load. Only in the Sind Valley did the stream finally reach the level of the third terrace, burying it with loose débris.

Fourth Glaciation

The fourth and least significant of the Pleistocene glaciations (fig. 150) is marked by several retreat stages, of which four could be distinguished for the Sind Glacier. Whether all of these belong to the last glaciation or whether the higher

two represent two postglacial stages is as yet unknown. Many of the troughs of these valley glaciers are insignificant channels scooped out by glacierets which deposited thin lateral and terminal moraines. Generally, the glaciers occupied only one-fourth, or a smaller fraction, of the valley tracts previously glaciated. Their small size enabled them more easily to register climatic variations by rapid melting of the snout and deposition of moraines. In the Pir Panjal none of the transverse valleys were glaciated; only their upper portions bore short ice tongues, which did not reach much below 11,000 feet. Nevertheless, glacial action and weathering provided sufficient detritus, which gradually formed the fourth terrace. Yet the thinness of the gravel thus deposited contrasts sharply with the thick accumulations of boulder gravel during the preceding glaciation. Now, as then, the streams finally carry the loamy silt which has been spread across the lowest terrace gravel. This brown or pink terrace loam is the last silty deposit which we can assign to glacial (or periglacial), eolian, and fluvial forces.

H. POSTGLACIAL GEOLOGY AND PREHISTORIC MAN IN KASHMIR

The retreat of the fourth glaciers and the formation of the last Pleistocene terrace mark a distinct change in the geologic history of the area. So far as observations allow a judgment, we do not believe that a major glaciation occurred in the immediate vicinity of the Kashmir Basin or in the upper Indus terrane during postglacial time. As stated above, Dainelli's fourth glaciation appears still to belong to the Pleistocene, and as for Finsterwalder's recent Nanga Parbat studies (1936), by which he dated the Himalayan glaciation as post-Pleistocene, one only has to look at a map in order to realize the peculiar position which the Nanga Parbat massif holds in respect to glacial phenomena. Perhaps these accounted for a variety of factors peculiar to this high massif. Its great altitude makes it an ideal catchment area for the monsoon rains, and any changes in precipitation should have been instantly recorded, resulting in an unusual variety of postglacial phenomena which would hardly be noticed in regions of lesser altitude. Moreover, as I have previously pointed out, this high massif is located at a structural interference of two major geanticlines, both of which have undergone repeated uplift in the Quaternary. The accumulated effect of these young uplifts is seen in the youthful dissection, making for steep valley gradients, which promoted glacial advance on the northern or leeward slope of Nanga Parbat. In this manner we view the post-Pleistocene glaciation of Nanga Parbat as determined by special factors which do not permit analogous conclusions, so far as the lower regions of Kashmir are concerned.

We doubt, however, whether the lesser glaciations of subrecent time were stronger here than in other regions of the Northern Hemisphere—certainly not in the northern tract, because of the increasing aridity of the area. The aridity may be due partly to the general decrease in rainfall, but it must also be affected by the growing height of the southern monsoon barriers. Almost all the highland lakes of Ladak and western Tibet have left unmistakable traces of a regional recession of the water table from high-water levels connected with the last Pleistocene

glaciations. Lakes Panggong, Yaye, and Mitpal Tso exhibit a great many beach levels of subrecent date which lie from 40 to over 100 feet beneath others attributed to the last glaciation. Western central Asia also recorded this increasing aridity, which no traveler has failed to notice.

This desiccation process of the postglacial epoch, however, was interrupted at times by wetter periods. The upper valley portions on both flanks of the Kashmir Basin have recorded these stages by small distinct terminal moraines. The following table illustrates their position (upper row) in relation to the fourth moraines of glacial age (lower row). The figures indicate altitude in feet.

Altitude in feet of postglacial and fourth glacial moraines

	Sind	Liddar	Harseni	Sokhnagh	Gulmarg	Ningle	Poonch
Postglacial terminal moraines.	10,500	11,500	11,085	12,500	?11,000	13,000	12,500
Fourth glacial moraines.....	8,800	9,200	8,760	9,300	9,000	9,600	10,500

In all these valleys the younger terminal moraines are distinguished from the older set (1) by their higher position, which in some of them is close to the lowest limit of present glaciation; (2) by their fresher state of preservation; (3) by their lesser thickness; and (4) by the selection of boulders derived from the nearest cirques. This glacial débris is clearly more closely associated with the recent moraines than with any belonging to the last glaciation. In the Sind and Tosh Maidan regions more than one moraine appears, but it is not clear whether these represent different retreat stages of the same glacier or short ice advances.

The postglacial terrace record suggests that there was at least one prominent postglacial advance. The fifth or lowest terrace, encountered in most valleys, is of depositional origin, as is the fourth terrace. Its boulder gravel filled the last channels that were cut after the retreat of the fourth glaciers. In some valleys this lowest terrace is still being inundated by seasonal floods, but more commonly it is an abandoned stream level, as the vegetative cover continues to thrive on it. The slope below T4 is 20 to 30 feet high, suggestive of a prolonged erosion interval, which presumably marks the first postglacial phase of deglaciation. In the plains, as also in the Kashmir Valley, T5 bears a slight loam cover, or else it is entirely composed of brown loamy silt. It is this deposit which overlies Upper Karewa lake clays on the Jhelum River near Pampur. The section in figure 151 shows that brown clay with implements (layer 2) overlies the lake beds at about 12 feet above the stream. This corresponds to the lowest terrace level found along the Jhelum and its tributaries, from which we conclude that the loam belongs to an early postglacial phase of aggradation. The overlying stratum is a porous loessic silt with dark clay bands mixed with pieces of charcoal. The presence of a clay figurine dates it as historic soil of the first millennium A.D., separated from the lower stratum by a disconformity. This superposition makes us suspect that the buried terrace level below is of more ancient date.

The implements from this terrace level have previously been described by Chr. and J. Hawkes (1934, p. 7) as flakes of Levallois type, and the inference drawn from this and earlier geologic observations was that we have here indications of middle paleolithic industries. However, in the light of more complete data, it would seem advisable to correct this view. First, the geologic age argues for a postglacial deposit, which is associated with T5. This makes the origin of the implements uncertain, as the flakes may have been washed out from an older stratum. Second, the presence of Levallois-like flakes is, under such circumstances, no proof for the existence of middle paleolithic man, because of the great time range of this typologic facies throughout Pleistocene and even postglacial epochs. Clear proof for the existence of flaking tradition in subrecent time was found during field work in 1935, when both Paterson and I recovered flakes with potsherds in alluvial deposits on the banks of the Jhelum, as well as in terrace sites of neolithic age.

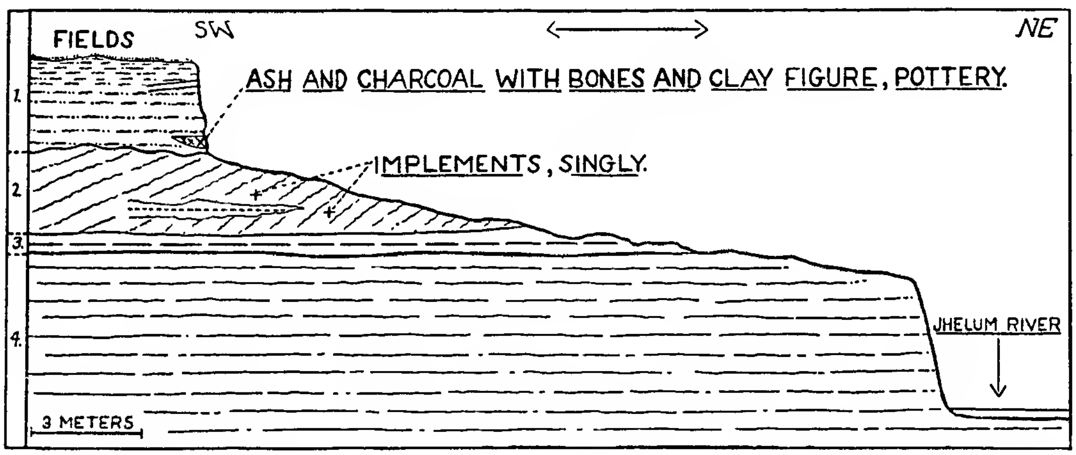


FIGURE 151.—Postglacial Jhelum terrace near Pampur. 1, Postglacial soil; 2, swamp deposit; 3, 4, Karewa clay.

Especially, the megalith site of Burzahom, between Srinagar and Gandarbal, yielded great numbers of artificially flaked stones, among which were flakes and cores reminiscent of paleolithic technique. Thin flakes were also found near Sombur in ancient soils covering the Upper Karewa terrace. In all these places it was certain that the flakes are associated with pottery-bearing layers of either neolithic or historic date. At Burzahom they are presumably waste products of an advanced Stone Age technique that aimed at the manufacture of hoes, pestles, and polished celts, which were found at depths ranging from 2 to 10 feet. Notwithstanding these observations, it is still possible that the flakes found in the lowest Jhelum terrace represent a late paleolithic or protoneolithic culture. This could be verified only by detailed archeologic studies.

Yellow loesslike soils are spread like a mantle all over the Karewa and younger terraces. At Burzahom a trial excavation was made in this soil, and a depth of 11 feet 8 inches was reached without striking the underlying Upper Karewa lake silt. Throughout this section were found potsherds belonging to a hard gray

ware with mat and rope design and finger-nail or thumb ornamentation. At 7 feet a kitchen level was struck with charcoal, polished celts, bone awls, and cooking pots. Paterson uncovered a similar settlement at Nunar, above Gandarbal, also 7 feet below the terrace surface. All this indicates that these neolithic sites were contemporaneous with the soil formation. Its fine porous nature and its distribution on higher ground where no river action was possible clearly indicate a wind-borne origin. In other words, the "neolithic soil" is a loess of postglacial age.

The association of a megalithic settlement with loess would enable us, for the first time, to fix the absolute age of a geologic formation in Kashmir, were it possible to date the neolithic site. Until further excavations are carried out in Kashmir we can only point out that the trial excavation at Burzahom disclosed the presence of at least two culture layers above the kitchen level (pl. XXIV, 2). The uppermost layer (A) contains potsherds belonging to the same Buddhist period as the site of Harwan, which represents the fourth century A.D. Below it lies a layer (B) with highly polished black ware and potsherds with incised geometric designs. This may belong to either a late or an early phase of the Indus Valley cultures, which range from 3000 to 1800 B.C. Both layers are only 2 to 3 feet thick and represent weathered loess mixed with rubbish derived from some sort of stone wall or foundation. Hence, the main loess below must antedate the upper cultures. At this time, when the age of the neolithic in India is unknown and estimates for the oldest agricultural period in Mesopotamia range from 4000 to 6000 B.C., it is hardly possible to make a reliable guess at the age of this loess culture.

Of importance for us is the fact that loess formation was not restricted to the glacial age but that it continued, as in northern China and Europe, into postglacial time. Whether this loess coincided with a dry or wet stage is difficult to tell, but the fact that the prehistoric sites lie on high terraces might possibly indicate a wet period which forbade settlements on lake shore or flood plains.

Interesting as these associations are in relation to the prehistory of Kashmir, one cannot help but proceed cautiously in the analysis of stray finds of artifacts. For instance, the single surface find of a patinated flake near Kargil (Hawkes and De Terra, 1934, p. 8) does not prove the former existence of paleolithic man beyond the Himalaya Range. The flake, which was made of trap and reworked at a later period, may have been carried by a prehistoric wanderer in subrecent times, or it may have been made by a member of the same people who settled on the lower Jhelum terrace near Pampur. Francke (1903, 1904) has described stone tools of recent manufacture from the upper Indus region in Ladak.

Considering that paleolithic man invaded the foothills in the Punjab and in Poonch as early as the middle Pleistocene, it may seem strange that similar records are lacking from Kashmir proper. It should be remembered, however, that the Pir Panjal at that time must have been dangerous ground for the prehistoric hunter of the old Stone Age. He would have preferred the lower grass lands to the alpine heights, especially because he came from peninsular India, where no mountain barriers of equal height and wildness arose on his migration routes. As long

as Kashmir is found lacking in true paleolithic antiquities, it must appear that early man did not discover it until the end of the Ice Age. Once the valleys were freed from ice and snow he may have ventured into the highlands for the pursuit of deer, bear, and fishing, to found a new type of existence from which may have sprung, ultimately, the agricultural age of civilization.

I. PETROLOGY OF THE KAREWA LAKE BEDS

By Paul D. Krynine[1]

A small suite of specimens from the Pleistocene deposits of the Karewa Lake, Kashmir, and adjacent territory was submitted to the writer by Dr. Hellmut de Terra for petrographic study and interpretation. The limited number of the samples and the generally small volume of many of them made it possible only to obtain an introductory insight into the fascinating genetic and paleoclimatic significance of these sediments. The present report hence is to be considered a preliminary one, intended only to give a broad outline of the Pleistocene history of the Vale of Kashmir as reconstructed from its lake deposits. It is also intended to show how the results of such a laboratory study can be tied up with the field evidence presented elsewhere in this volume by Dr. de Terra.

The writer is indebted to Dr. de Terra for helpful comments during the preparation of this manuscript. Financial assistance from the Carnegie Institution of Washington helped to bring this study to a successful conclusion.

For the sake of clarity and in order to make this paper as interesting as possible to the nonprofessional petrographer, the usual procedure of giving long and exhaustive descriptions before attempting to generalize has been reversed. The conclusions and the genetic significance of the Karewa deposits is given first, and the somewhat tedious purely petrographic material follows.

SEDIMENTATION AND GENETIC SIGNIFICANCE OF THE KAREWA DEPOSITS

The Karewa sedimentary suite consists of 15 Pleistocene sediments from Kashmir, northern India. The samples have been numbered from 1 to 15 and arranged in a stratigraphic column according to the information supplied by Dr. de Terra. The significance of Dr. de Terra's horizons is discussed elsewhere in this volume. A summary of the mechanical analyses and the content of calcium carbonate is presented in table 1. The petrographic data and a tabulated summary of some of the conclusions are presented in table 2. Stratigraphic interpretations are shown in table 3. A detailed description of each specimen precedes the tables.

The mechanical analyses were made by the wet Bouy-Casagrande hydrometer method. Thin sections and both light and heavy residues were studied as far as it was practicable in the absence of a centrifuge.

General character of the suite.—The rocks are fine-grained silty sediments. Most of the specimens (10 pieces) are fine silts; four samples are impure calcareous rocks, and one (no. 3) is a very peculiar micrograywacke (or lignitic microcon-

[1] School of Mineral Industries, Pennsylvania State College, State College, Pa.

glomerate), rich in organic matter. Not a single specimen can be called a true clay, even the finest-grained sample (no. 8) having a median diameter of 6½ microns, and the amount of clayey material in it reaching only 36 per cent.

The sorting and sizing are generally poor, in some specimens extremely so. Banding, lamination, and other sedimentary structures are well developed in only three or four samples; otherwise they are obscure or altogether absent.

Calcium carbonate is a very abundant constituent. Its degree of abundance seems to be definitely related to certain stratigraphic horizons (tables 1 and 3). The organic content of some of the specimens is high and organic matter occurs in two-thirds of the suite.

The mineral constituents.—The fundamental mineral component of most samples is a quartzose or quartzose-feldspathic silt. Upon this background are superimposed large amounts of micaceous material (mostly near the top of the series), numerous iron ores, usually leucoxene and ilmenite-leucoxene, and finally a variable suite of 19 nonopaque heavy minerals. The small number of specimens did not warrant a quantitative treatment for purposes of correlation. Qualitatively, however, on the basis of the heavy mineral species per se and of their varietal character, it is possible to distinguish between mineral suites of igneous, metamorphic, normal sedimentary, and red-beds provenance. The material from the red beds is restricted to the upper part of the section; the igneous material to the lower part. Metamorphic rocks and non-red-bed sediments occur at many levels, but the sedimentary source is felt especially in the upper part of the section, the metamorphic in the lower and middle parts. The presence of residual chert indicates that limestones were being eroded either at or below the level of occurrence of the chert.

The degree of wear of the grains is highly variable, but the shape of most grains ranges between subangular and angular. This, however, is normal in all finer-grained sediments, which always are notoriously wear-resisting. Hence, a true picture of the degree of abrasion and wear can be obtained only from the coarsest silt or sand fractions of the specimens, which usually form only a very small percentage of the total amount. Some specimens, nevertheless, show definite signs of glacial action, others of eolian transport.

Paleoclimatic criteria.—Inasmuch as the sedimentary record is the result of dynamic processes rather than of a static environment, the petrographer must remember, when making his interpretations, that many sedimentary processes are not restricted to one single environment. Hence cumulative evidence and the dominant characteristics of a sediment must be sought rather than some possibly very conspicuous but actually unimportant "pseudocrucial" criteria. On the basis of the work done by the writer on glacial sedimentation both in New England and in the Pacific Northwest,[1] coupled with a thorough study of the literature, it is believed that glacial, lacustrine, fluvial, and eolian deposits can be differentiated

[1] Krynine, P. D., Glacial sedimentology of the Quinnipiac-Pequabuck lowland in southern Connecticut, Am. Jour. Sci., 5th ser., vol. 33, pp. 111–139, 1937; Age of till on "Palouse soil" from Washington, ibid., pp. 205–216; several more papers in preparation.

with a fair degree of success on the basis of the criteria offered in this publication. A prerequisite for this is a certain familiarity with the general lithology of the region. A study of Tertiary fluvial deposits of the Punjab, which reflected the lithology of the Himalayas, provided such information.

If the original starting constituents—the Paleozoic metamorphic rocks of the Himalaya Range and the Tertiary limestones, sandstones, and red beds—are known, subsequent modifications by either fluvial, glacial, lacustrine, or eolian transport can be visualized. The ultra-angularity (raggedness) due to glacial action and the extremely rapid rounding process of glaciofluvial and especially lacustrine action are frequently unmistakable. So are the regular structure of lacustrine beds and the heterogeneity and lack of rounding of eolian loesses. The presence of beidellite and of incipient ferruginous concretions is a good way of separating loess, even partly bedded pluvial loess, from deposits formed in water bodies.

On the basis of these and other criteria which are discussed more fully in the detailed descriptions, an interpretation of the sediments and also a reconstruction of the events that led to the formation of these sediments are offered below.

Interpretation of the sediments.—With the exception of the topmost samples (13, 14, 15), which appear to be subaerially deposited eolian loess, all the specimens are of lacustrine or paludal origin. The material that came to rest in these lakes was brought partly by streams and partly by wind transport. There seem to be two well-defined horizons of eolian transport, a problematic third one, and apparently also two horizons at which fluvial transport predominated.

Some of the material brought into the lakes by the wind or the streams had been previously modified by glacial action. Glacial material is sporadically present throughout the section, but it is especially prominent in the middle part of it. It is somewhat difficult to correlate this glacial material with any definite periods of ice advance, because it is essentially not primary, but reworked, and hence its deposition in the Karewa Lake may either have been contemporaneous with an ice period (periglacial), or have followed one (interglacial or postglacial). The fact that some of the most prominent glacial material (as in no. 6) is found in a markedly weathered deposit complicates this problem still further.

The zones of weathering indicate mild interglacial periods at or above the horizons where they are found. Recrystallized and secondary calcite, authigenic barite, and other evidences of diagenesis do not have much climatic significance, because they are due mostly to the action of circulating waters.

Genetic significance of the sediments and paleogeography.—With the limitations mentioned in the preceding section kept in view, the following picture of past events, as reflected in the Kashmir sediments, can be tentatively offered.

Alpine conditions with valley lakes fed by streams coming from mountain tops subject to frost action (or even partly glaciated) probably existed during Tatrot time.

When the overlying Lower Karewa beds were laid down, somewhat milder climatic conditions may have prevailed. Fluvial transport appears to have been concomitant with the eolian deflation of preexisting outwash plains.

As the Lower Karewa beds pass into the Upper Karewas, the presence of glacially modified material becomes more and more noticeable. Later on, in the later part of Karewa time, milder climatic conditions appear to have prevailed.

The top of the section consists of eolian silts. Specimen 13 appears to be a fair illustration of the pluvial loess of De Terra. The other two samples of Potwar silt, although decidedly loessic, cannot be assigned with certainty, on the basis of their petrography, to either a pluvial or an ordinary (nonpluvial) method of deposition.

Up to the middle of the Upper Karewa group the general lithology shows a preponderance of metamorphic material in the source area, with only subordinate sedimentary areas being eroded. The upper part of the section, on the other hand, consists almost exclusively of sedimentary and especially red-bed detritus. The deflation of large postglacial or periglacial outwash plains and the erosion of older sedimentary sections, exposed during the southern progress of Himalayan orogeny, probably both account for this fact.

DESCRIPTIVE PETROGRAPHY

Specimen 1

Location.—Tatrot clay, Naushahra, Salt Range.

Field name and correlation.—Clay; Tatrot age, early Pleistocene, correlated with the first ice advance. (Field sample 23.)

Megascopic appearance.—Light-buff, finely banded fine-grained sediment, somewhat gritty; parallelism of banding not very good; contains rare shell fragments.

General composition.—

Soluble in cold HCl ($CaCO_3$)	67.93 percent
Insoluble residue	32.07

Mechanical analysis of insoluble residue (condensed).—

Sand	0.3 percent
Coarse silt	33.7
Fine silt	41.1
Clay	21.8

Microscopic examination.—Subparallel wavy laminations due to varying amounts of organic content are faintly visible. Plant (?) remains are mostly arranged parallel and elongated.

The insoluble material is so intimately mixed with the calcite that a contemporaneous precipitation of both appears probable. A very few calcite grains show, however, some incipient recrystallization. Incipient dolomitization appears also to have taken place.

Among the mineral grains quartz is the most prominent. Most of the quartz is angular, some of it extremely so, forming splinters (Cayeux's éclats), suggestive of glacial action. Other minerals present are microcline, muscovite, biotite, limonite, leucoxene, and among the rare heavy minerals hornblende (the most common of the heavy minerals, often ragged and splintery in appearance), fluorite (also abundant), and in smaller amounts anatase, barite, chlorite, large ragged garnet fragments, titanite, and zircon, a mineral suite of mixed igneous and metamorphic derivation.

Wood fragments, aggregates of colloids, diatoms (several species), and pollen (apparently not less than two varieties) complete the composition of the insoluble residue.

Name and probable genesis.—The rock is a silty marl, apparently formed in a lake rich in calcium carbonate and possessing currents sufficient to disturb and crumple the bottom sediments before

consolidation. The temperature must have been adequate to support animal and vegetable life. The splintery appearance of many of the minerals suggests powerful abrasion, possibly from glaciated mountain tops not far away, and a relatively short and turbulent transport prior to sedimentation.

Specimen 2

Location.—Naushahra, Salt Range.

Field name and correlation.—Diatomaceous (?) silt of Tatrot age, correlated with the first ice advance. (Field sample 22.)

Megascopic appearance.—Very pale buff, almost white, porous, very fine-grained sediment, somewhat gritty to the touch, showing no visible stratification and an irregular fracture in a small hand specimen.

General composition.—

Soluble in cold HCl ($CaCO_3$)	91.20 percent
Insoluble residue	8.80

Mechanical analysis of insoluble residue.—Could not be made owing to insufficient amount of insoluble residue.

Microscopic examination.—The rock consists of a calcareous paste, made up of a mosaic of very small calcite grains (0.003–0.004 mm in diameter) in which are embedded a few larger grains (maximum 0.1 mm) of calcite. Some of these larger grains are due to recrystallization, showing twinning and orientation along fissures; in places they contain clusters of smaller grains.

As a whole the calcareous material shows no evidence of organic structure. The rock itself is almost structureless, only indistinct curved bands appearing to be present at some places. Incipient (although very faint) dolomitization is present.

The insoluble residue consists, to the extent of 80 percent, of a dark, unresolvable dust less than 0.001 mm in diameter, possibly of organic origin. The balance (20 percent) is made up of diatom shells, with at least eight varieties present. Most of the shells are broken. Not more than 1 percent is made up of mineral grains, mostly quartz (average diameter 0.02 mm, maximum diameter 0.7 mm). The degree of rounding of the quartz is variable, from well-rounded to very angular.

Other minerals are rounded brown tourmaline (0.035 mm in diameter) and angular greenish-blue tourmaline.

Name and probable genesis.—The rock is a diatom-bearing limestone precipitated probably under conditions of rapid acyclical deposition. No definite climatic inferences can be made from this sediment.

An older sedimentary series was being eroded at this time and supplied some of the sediment that came to rest in this lake.

Specimen 3

Location.—Laradura, Kashmir.

Field name and correlation.—Lower lignite series, zone 2, Lower Karewas, correlated with the first interglacial stage. (Field sample 53.)

Megascopic appearance.—A grayish-black gritty, fine silty sediment, containing sand grains and even small pebbles as much as 1 by 0.75 cm in diameter and a considerable amount of organic matter. No discernible bedding.

General composition.—Practically no $CaCO_3$ present.

Mechanical analysis (condensed).—

Sand	21.0 percent
Coarse silt	25.4
Fine silt	29.3
Clay	23.0

Microscopic examination.—The rock is a microconglomerate, a structureless, almost till-like jumble of grains of different sizes embedded in a dark organic matrix. The grains form 20 to 25 percent of the mass, the organic matter 40 percent, and the balance is made up of finer clayey and colloidal material.

Among the pebbles and rock fragments present in one thin section, the following rock types were recognized:

1. Two varieties of mica schist.
2. A sandstone, made up of larger grains embedded in a finer sandy matrix, partly sericitized.
3. An altered quartz porphyry (rhyolitic) showing flow structure.
4. An epidotized quartzitic mica schist.
5. Two types of very fine-grained quartzite.
6. A phyllite or high-rank slate.
7. A coarse-grained quartzite.
8. A sericitized undeterminable contact rock.

All the pebbles show from fair to considerable weathering, and almost all are rounded or subangular. Some of the pebbles in the rock are triangular, possibly suggesting that they may be ventifacts(?).

The smaller mineral grains (below pebble size) are mostly subangular, with minor amounts either rounded or angular or even very angular. They consist mostly of quartz.

A petrographic analysis shows the following composition for the fine-sand fraction (0.25 mm):

Quartz	48 percent
Phyllite schist and sericitic rock fragments	35
Wood fragments	14
Feldspar	3

The relative angularity of the quartz and phyllite-schist suites is as follows:

	Quartz suite	Phyllite suite
Very angular	5 percent	0 percent
Angular	20–25	5
Subangular	70	55–60
Rounded	1–2	40

These comparative figures indicate a relatively short fluvial transport, sufficient to round well the softer material (schists, phyllites) but insufficient to affect very much the more resistant quartz grains.

The heavy minerals include anatase, andalusite, chlorite, chloritoid, barite, epidote (most abundant), garnet, kyanite, hornblende, leucoxene, yellow rutile, tourmaline, and zircon. The suite is angular to subangular in shape.

Name and probable genesis.—An organic micrograywacke or a microconglomerate lignite appear to be the most appropriate terms to be applied to this rock. It was formed from material normally weathered, eroded, and fluvially transported for a relatively short distance (probably much less than 50 miles, possibly only a fraction of that figure). Deposition was extremely abrupt, resulting in a complete lack of sorting and sizing and the formation of a heterogeneous, structureless sediment. From the abundance of organic matter and wood, the environment prevailing at the place of deposition appears to have been near the shore of a swamp or the marshy shore of a lake into which debouched a series of rather swiftly flowing small or medium-sized streams. The climate appears to have been temperate-humid. The source of the sediments was close at hand and included a large number of rock types, with metamorphic rocks predominating.

Specimen 4

Location.—Shore deposit of Karewa Lake, Sombur, Kashmir.

Field name and correlation.—Littoral bone beds, zone 2, correlated with the first interglacial period. (Field sample M-6.)

Megascopic appearance.—Very fine-grained yellowish-buff sediment containing numerous shells and very few small pebbles, among which potassium feldspar fragments and dark pellets can be recognized. Bedding is poor or almost absent. Limonitic stains are present.

General composition.—

Soluble in cold HCl ($CaCO_3$)	23.77	percent
Insoluble residue	76.23	

Mechanical analysis of insoluble residue (condensed).—

Sand	2.1	percent
Coarse silt	25.5	
Fine silt	53.5	
Clay	17.1	

Microscopic examination.—The rock is an almost structureless microconglomerate containing from 5 to 10 percent of large sand grains and shell fragments embedded in a ground mass consisting of a gradational series of finer sand grains and rock flour (50 percent) and recrystallized colloidal matter (40 percent).

Among the granules and larger grains are angular to subangular grains of quartz, feldspars (some fresh and splintery, others showing kaolinization), and pieces of isotropic silica.

Among the heavy minerals the most prominent is a flood of authigenic barite, and the next most abundant are kyanite and epidote. Other minerals present include muscovite, chlorite, chloritoid, zoisite, hornblende, yellow rutile, rounded pink and brown tourmaline, and very small amounts of garnet and zircon. Except the tourmaline all these minerals are subangular to angular, some of them extremely so.

Most of the calcium carbonate seems to be localized in the shell fragments (65 to 80 percent).

Name and probable genesis.—The rock is a fossiliferous calcareous fine silt, possibly in large part air-transported (eolian loess), but water-laid near the shore of a periglacial or interglacial water body, and subjected to rather considerable weathering in place and diagenetic changes after deposition. The deflated source area was rich in metamorphic rocks but contained only a small amount of sedimentary formations exposed to erosion. This suggests short transport or steady wind direction, or both, during the period of deposition.

Specimen 5

Location.—Dudhganga Valley, Kashmir.

Field name and correlation.—Laminated Lower Karewa clay in zone 3 (upper lignite series).

Megascopic appearance.—Pale-yellowish to grayish-buff fine-grained rock, semiunctuous to the touch, showing banding and lamination 0.5 to 5 mm apart.

General composition.—

Soluble in cold HCl ($CaCO_3$)	39.16	percent
Insoluble residue	60.84	

Mechanical analysis of insoluble residue (condensed).—

Sand	0.2	percent
Coarse silt	37.1	
Fine silt	43.1	
Clay	20.6	

Microscopic examination.—The constituents show a fair to poor arrangement parallel to the bedding, which accounts for the banding. Some of the coarser grains, however, cut across it. The material, mostly micaceous in composition, shows a seriate grading and sizing. The finest paste is very pale buff and appears to be made up of recrystallized colloids, possible beidellite-like in composition. The calcite is finely disseminated throughout the rock, very little of it showing recrystallization.

The dominant mineral grains consist of quartz, chert, chalcedony, microcline, and altered plagioclase. Muscovite is very abundant, biotite is rare. The heavy minerals include hornblende, kyanite, garnet, epidote, sillimanite, chlorite, zircon, barite, and leucoxene. All the mineral grains are subangular to angular, some of them extremely so. In addition, diatoms, scarce pieces of vegetable tissue, and large pollen grains are present.

Name and probable genesis.—The rock is a fine calcareous clayey silt consisting apparently to a large extent of wind-borne material which was water-laid in a periglacial or interglacial lake, but farther off-shore than sample 4. Both samples are otherwise rather similar. Most of the material of this specimen was also derived from a metamorphic terrane. However, this sample shows much less postdepositional alteration and diagenetic change than specimen 4.

Specimen 6

Location.—Baramula, Kashmir.

Field name and correlation.—Plant beds in zone 4, Lower Karewa. (Field sample K-25.)

Megascopic appearance.—Pale-buff gritty fine-grained sediment, poorly laminated, with a few visible organic remains (plants) and small orange spots.

General composition.—

Soluble in cold HCl ($CaCO_3$)	11.40 percent
Insoluble residue	88.60

Mechanical analysis of insoluble residue (condensed).—

Sand	2.3 percent
Coarse silt	64.0
Fine silt	23.5
Clay	10.2

Microscopic examination.—A poorly oriented, heterogeneous mixture of coarser material (60–65 percent) embedded in a very fine pasty matrix (35–40 percent). From 60 to 70 percent of the coarser material consists of mineral grains, the balance (30 to 40 percent) of organic specks. The paste is made up of 20 to 30 percent of organic material and 70 to 80 percent of a yellowish-buff recrystallized colloidal substance, apparently similar to beidellite. The calcite in the rock is finely disseminated and is almost invisible.

The mineral grains are very angular and ragged, including the larger ones (maximum size 0.4 by 0.1 mm). They consist of quartz, chert, altered feldspar, muscovite, biotite (showing various degrees of weathering), abundant leucoxene, authigenic barite, authigenic euhedral anatase, hornblende, chlorite, chloritoid, staurolite, kyanite, epidote, and zoisite. Diatom casts and a large amount of unrecognizable organic matter are also present.

Name and probable genesis.—The rock is a coarse silt, somewhat calcareous. It was water-laid under conditions of rapid precipitation but possibly is made up of wind-borne material deflated from a metamorphic source area where the constituents had been loosened by glacial abrasion. It appears, hence, to be a periglacial deposit, formed, however, sufficiently far away from the glacier to insure relatively mild climatic conditions and subjected later to a small amount of postdepositional weathering in place.

Specimen 7

Location.—Laradura, Kashmir.

Field name and correlation.—Plant-bearing clay in zone 4, Lower Karewa. (Field sample M-31.)

Megascopic appearance.—A pale yellowish-gray, very fine-grained semiunctuous sediment with a conchoidal fracture. Lamination and bedding are indistinct. Dark-brown spots 1 to 2 mm in diameter are present, forming a subparallel pattern.

General composition.—Insoluble in cold HCl; only very weak effervescence takes place.

Mechanical analysis (condensed).—

Sand	0.0 percent
Coarse silt	16.7
Fine silt	53.5
Clay	28.8

Microscopic examination.—The rock is made up of approximately 25 percent of mineral grains, diatom shells, and plant remains embedded in a finer matrix (75 percent) made up of silty and clayey paste. This paste, most of which is almost optically inert, consists approximately of 40 percent of organic matter and 60 percent of a micaceous material made up principally of clayey minerals, optically indeterminable. Many of these micaceous flakes are in optical continuity.

The plant remains show a fairly good parallel elongation and arrangement along the bedding planes. Some of the bedding planes are curved, suggesting movements in the soft mud before consolidation.

The mineral grains include quartz, feldspar, chlorite, epidote, garnet, greenish-blue tourmaline, and zoisite. There is no fresh rock flour, the average mineral grain approaching 0.02 mm in diameter, the largest reaching 0.25 mm. There are no rounded grains, approximately two-thirds being angular and one-third subangular. A tourmaline grain 0.057 mm in diameter shows an extraordinarily jagged contour.

In addition to plant remains and the fine organic dust, at least five species of diatoms, algae, and pollen grains are present.

Name and probable genesis.—The rock is a very fine organic clayey silt, water-laid under lacustrine conditions with gentle bottom currents sufficient to disturb the beds of soft ooze before consolidation. Very little of the material shows direct glacial derivation, although a large part of it may have been produced through the reworking of an earlier glacial deposit. A periglacial or rather mild interglacial climate appears to have prevailed during the deposition of this sediment.

Specimen 8

Location.—Pampur, Kashmir.

Field name and correlation.—Upper Karewa plant-bearing clay in zone 2. (Field sample K-17.)

Megascopic appearance.—Pale grayish-yellowish, very fine-grained sediment, semiunctuous to the touch. No evidence of bedding. Dark reddish-brown spots as much as 1.25 by 0.3 cm in diameter are present.

General composition.—Insoluble in cold HCl; shows only very weak effervescence.

Mechanical analysis (condensed).—

Sand	0.0 percent
Coarse silt	15.0
Fine silt	46.7
Clay	35.5

Microscopic examination.—The rock is made up mostly (95 percent) of very angular mineral grains and rock flour, with only a very small amount of organic matter. Only quartz, feldspar,

and biotite were recognized, for, in the absence of a centrifuge, the heavy minerals could not be extracted from this very fine-grained sediment. No diatoms or pollen were found. The reddish spots are limonitic stains either related to slightly altered biotitic areas or infiltrations along the poorly marked bedding planes.

Name and probable genesis.—The rock is a water-laid fine clayey silt, probably of glacial derivation and subjected to a small amount of weathering after deposition.

Specimen 9

Location.—Pampur, Kashmir.

Field name and correlation.—Upper Karewa plant-bearing clay in zone 2, correlated with second interglacial period. (Field sample K-46.)

Megascopic appearance.—Pale yellowish-gray fine-grained semiunctuous sediment, showing irregular fracture and very poor stratification. Pale-orange limonitic stains are present, apparently along bedding planes and in the vicinity of organic remains.

General composition.—

Soluble in cold HCl ($CaCO_3$)	27.95 percent
Insoluble residue	72.05

Mechanical analysis of insoluble residue (condensed).—

Sand	1.1 percent
Coarse silt	22.0
Fine silt	66.8
Clay	10.9

Microscopic examination.—The rock consists of very fine micaceous flakes, showing a parallel to subparallel arrangement. There is an appreciable amount of biotite, part of which is bleached.

The calcite is mostly finely disseminated (80 percent); partly (20 percent) it occurs as larger recrystallized bodies, 0.12 mm in maximum diameter. Incipient dolomitization is to be noted, with dolomite rhombs as large as 0.075 by 0.05 mm present.

Among the larger sand grains (largest one 0.7 mm in diameter) the most conspicuous member is altered feldspar, which outnumbers quartz 2 to 1. Chert is present. Muscovite is abundant, biotite less so. Secondary euhedral anatase is present. The other heavy minerals include dark-green hornblende (much of it showing alteration), kyanite, chlorite, staurolite, epidote (some euhedral), and leucoxene—a metamorphic assemblage.

Most of the grains are subangular, although some are angular. As a whole, however, the suite shows much more wear than is usual in Karewa specimens. Diatom shells and large reddish pollen grains are present.

Name and probable genesis.—The rock is a very fine clayey calcareous silt, normally water-transported and water-laid, with only a very slight contribution (if any) of eolian material. Most of the weathering was predepositional, although some postdepositional weathering took place. Deposition apparently was acyclical in a lake rich in calcium carbonate.

Specimen 10

Location.—Baramula, Kashmir.

Field name and correlation.—Plant-bearing clay in zone 2, Upper Karewa. (Field sample M-7.)

Megascopic appearance.—Very pale yellowish-gray fine-grained sediment, semiunctuous to gritty, showing poor banding and containing numerous calcareous fossil shells as much as 5 by 3 mm in size.

General composition.—

Soluble in cold HCl ($CaCO_3$)	15.60 percent
Insoluble residue	84.40

Mechanical analysis of insoluble residue (condensed).—

Sand	5.7	percent
Coarse silt	49.1	
Fine silt	34.3	
Clay	10.9	

Microscopic examination.—A poorly stratified rock consisting of a mixture of shell fragments, minute rock fragments (mostly epidotized quartz schist), numerous quartz grains, and a little feldspar (sodic oligoclase) in a finer matrix of clayey and colloidal matter. There is relatively little mica.

The heavy minerals include actinolite, chlorite, epidote, hornblende, kyanite, sillimanite, staurolite, pale apple-green tourmaline (rounded), zircon, and yellow rutile in the form of geniculated twins. This is a mixed suite, showing complex derivation.

The rounding of the minerals, especially of the larger grains, is fair to good, even in quartz. Notable are the rounding of tourmaline and especially of kyanite, which occurs in grains as large as 0.55 by 0.8 mm. The smaller mineral grains are fresher and show a greater degree of angularity, as is to be expected.

Name and probable genesis.—The rock is a fossiliferous coarse silt deposited in a lacustrine environment under conditions of acyclical precipitation and of gentle but permanently flowing currents. Of special diagnostic significance in this respect is the rounding of kyanite: this very hard but very brittle mineral requires wear by prolonged but gentle water currents; otherwise instead of being rounded it splits along cleavage planes.

It is suggested that at this stage the drainage system emptying into the lake was sufficiently developed to tap several source areas—one relatively close at hand, consisting of metamorphic rocks that had been subjected to weathering before erosion and deposition, and a more distant one, less weathered and containing in addition to metamorphic material also sedimentary formations. A relatively normal, humid climate appears to have been prevailing during this period.

Specimen 11

Location.—Pampur, Kashmir.

Field name and correlation.—Marl-bearing concretionary silty clay in zone 3, Upper Karewa, correlated with the second interglacial period. (Field sample K-19.)

Megascopic appearance.—Pale yellow-gray fine-grained gritty sediment containing elongated gray calcareous concretions as large as 2.5 by 1.0 cm.

General composition.—

Soluble in cold HCl ($CaCO_3$)	77.53	percent
Insoluble residue	22.47	

Mechanical analysis of insoluble residue (condensed).—

Sand	1.4	percent
Coarse silt	54.3	
Fine silt	32.2	
Clay	11.9	

Microscopic examination.—The rock consists of isolated mineral grains embedded in a fine mosaic of calcium carbonate, partly recrystallized. There is a small amount of organic matter.

Quartz is the most abundant of the mineral grains. Most of the quartz grains are clean; some, however, are coated with red iron oxide, implying a derivation from preexisting red beds. A few quartz grains show corrosion. Most of the feldspar grains show replacement by calcite in various stages of progress. Limonite grains derived from the alteration of pyrite are present. Other iron ores are magnetite, ilmenite, and leucoxene. Micas are very abundant, biotite pre-

dominating over muscovite in the ratio of 2 to 1. Chlorite is relatively abundant. Other heavy minerals are chloritoid, hornblende, sillimanite, and staurolite—a typical metamorphic assemblage. Authigenic euhedral colorless anatase is also present. The mineral grains are subangular.

Dubious shells of diatoms (?) are very rare.

Name and probable genesis.—The rock is a concretionary silty marl, almost a very impure limestone. It was formed through the deposition of silt in a lake containing carbonates with a considerable amount of diagenetic changes, alteration, and further considerable enrichment in carbonates by circulating waters. The source area that supplied the sediment appears to have been mostly metamorphic and either very small in extent or very poor in rock types (apparently chlorite and mica schists). The transport seems to have been relatively short. Some of the material may have been of glacial derivation.

Specimen 12

Location.—Burzahom, Kashmir.

Field name and correlation.—Marl in Upper Karewa clay. (Field sample 47.)

Megascopic appearance.—Pale-gray fine-grained semigritty sediment, showing fair laminations and somewhat micaceous.

General composition.—

Soluble in cold HCl ($CaCO_3$)	71.87 percent
Insoluble residue	28.13

Mechanical analysis of insoluble residue (condensed).—

Sand	0.0 percent
Coarse silt	13.6
Fine silt	61.7
Clay	24.8

Microscopic examination.—The rock consists of subordinate mineral grains and mica flakes (consisting of recrystallized colloids?) embedded in a fine-grained mosaic of calcium carbonate, which shows very little recrystallization. Small, irregular nests of organic matter are locally present.

Among the larger grains a very small fragment of weathered quartzitic mica schist and quartz grains, some of them iron-coated, are present. Other minerals include biotite, garnet, kyanite, and colorless or brown tourmaline—a suite pointing to a mixed derivation. The mineral grains show variable angularity; a few are euhedral, suggesting eolian action as a possible contributing source of transport. Limonite, possibly replacing pyrite(?), is present.

As a whole, the rock shows a definite microbanding, almost varvelike, due to cyclical changes in grain size and in organic content of the different layers.

Name and probable genesis.—The rock is intermediate between an impure marly limestone and a fine clayey calcareous marl. It appears to be mostly a chemical deposit deposited in a cyclical (seasonal) lacustrine environment together with fine silt partly of normal fluvial origin and subordinately of eolian origin. The source area consisted of both metamorphic and sedimentary rocks, including a red-bed series.

Specimen 13

Location.—Wular Lake, Kashmir.

Field name and correlation.—Uppermost soil layer, Upper Karewa clay in zone 4. (Field sample K-34.)

Megascopic appearance.—A buff to pale-yellowish fine-grained sediment, in places chocolate-brown and showing a conchoidal fracture.

General composition.—

Soluble in cold HCl ($CaCO_3$)	19.73 percent
Insoluble residue	80.27

Mechanical analysis of insoluble residue (condensed).—

Sand	0.0 percent
Coarse silt	40.4
Fine silt	41.0
Clay	18.4

Microscopic appearance.—The rock is essentially a structureless, heterogeneous mixture of mineral grains in a buffish mass of recrystallized colloids (possibly beidellite), with a very weak, incipient beginning of the formation of minute iron oxide concretions.

The calcite occurs as concretions and bands; it is of secondary origin.

Among the mineral grains quartz is prominent, much of it being iron-coated. Microcline and chert are present. Muscovite is not very abundant, and there is very little biotite. Iron ores (magnetite, ilmenite, and leucoxene) are conspicuous. Among the heavy minerals are epidote, titanite, zircon, and authigenic barite—an assemblage suggesting an igneous or igneous-sedimentary derivation. The rounding of the grains is fair, some being well rounded indeed and all qualifying for a place between the subangular and moderately rounded classes. Weathering of the grains is also notable. A few diatoms are present.

Name and probable genesis.—The rock is a fine silt of somewhat dubious origin. The structureless character suggests eolian deposition, possibly rapid, in a body of water which may have been temporary, coexistent only with a rainy period. This would fit in with De Terra's hypothesis of a "pluvial loess." The character of the postdepositional weathering also suggests a loess, being reminiscent of that of the Palouse soil of Washington. The rounding of the mineral grains, however, suggests either water transport or the deflation of a preexisting, already well-rounded sedimentary series. Probably the deposit is of complex origin, being a deflated mixture of wind-borne and water-borne material. The source area consisted mostly of sedimentary rock and included red beds. Diagenetic changes and weathering in a moderately humid and cool climate followed.

Specimen 14

Location.—Soan Valley, near Rawalpindi.

Field name and correlation.—Reddish Potwar silt, correlated with the third ice advance.

Megascopic appearance.—A reddish-pink gritty structureless siltstone, weakly consolidated and showing a few shining flakes of mica.

General composition.—

Soluble in cold HCl ($CaCO_3$)	18.70 percent
Insoluble residue	81.30

Mechanical analysis of insoluble residue (condensed).—

Sand	2.2 percent
Coarse silt	60.9
Fine silt	26.9
Clay	11.0

Microscopic examination.—The rock consists of a structureless, heterogeneous jumble of grains of various sizes, mixed pell-mell in a very subordinate matrix of clayey and colloidal material.

The red color is due mainly to the abundance of quartz grains with a primary iron oxide coating. Very little of the color is caused by postdepositional "running" of the iron-bearing minerals. The calcite occurs in small nodules as much as 0.12 mm in diameter. It appears to be secondary.

In addition to quartz (both clear and iron-coated) there are some altered feldspar and a very great abundance of mica. The proportion of muscovite to biotite is 60 to 40. The iron ores consist of limonite and hematite. The heavy minerals include barite, chlorite, epidote, garnet, horn-

blende, kyanite, sillimanite, staurolite, and several varieties of tourmaline (bluish, brown, pale yellow, and colorless with numerous minute dark inclusions; this last variety is rather typical of phyllitic rocks). This is a suite of decidedly mixed derivation.

The angularity is very variable; most of the material shows moderate rounding, although some of the larger hornblende grains (0.47 mm in diameter) are ragged.

Name and probable genesis.—The rock is a wind-borne, subaerially deposited coarse silt (eolian loess). The deflated area was rich in rock types, with a sedimentary series predominating and metamorphic rocks subordinate. Red beds were the main deflated formation. Some of the material may have been loosened up by glacial abrasion before deflation. The winds appear to have been steady in direction and strong in character, to judge by the relative coarseness of the deposit. Only little alteration took place after deposition.

Specimen 15

Location.—Damlial, near Rawalpindi.

Field name and correlation.—Potwar silt, correlated with the third ice advance. (Field sample P-5.)

Megascopic appearance.—A structureless pale yellowish-gray fine-grained semiunctuous gritty siltstone, showing flakes of mica.

General composition.—

Soluble in cold HCl ($CaCO_3$)	19.38	percent
Insoluble residue	80.62	

Mechanical analysis of insoluble residue (condensed).—

Sand	1.2	percent
Coarse silt	43.3	
Fine silt	42.2	
Clay	13.2	

Microscopic examination.—A structureless, heterogeneous jumble of mineral grains mixed pell-mell with yellowish recrystallized colloidal matter (beidellite?). Much of the calcite is disseminated; some of it occurs in nodules.

Most of the quartz grains are clear and uncoated, but a few are coated with iron oxide, thus establishing their derivation from red beds. Chert and feldspar are also present. The feldspar is mostly microcline in various degrees of alteration. Micas are extremely abundant. Muscovite forms 70 percent of the mica, biotite 30 percent. The biotite shows very little alteration. In addition to the iron ores (magnetite, ilmenite, and leucoxene) the following heavy minerals were found: chlorite, garnet, hornblende (largest grain 0.48 by 0.21 mm), staurolite, titanite, reddish-green tourmaline, and zoisite.

Large reddish grains of pollen and problematic diatom shells are present. The angularity of the grains is widely variable, although most are subangular to rounded.

Name and probable genesis.—The rock is a wind-borne, subaerially deposited silt (eolian loess) very similar to sample 14 except that it contains much less material derived from red beds. It shows a somewhat greater amount of postdepositional alteration than sample 14, but not very much at that. The source area that supplied the deflated material apparently consisted mainly of sedimentary formations but was poorer in rock types than that of sample 14. The intensity of the wind may have been less than in the area from which sample 14 was derived.

TABLE 1.—*General constitution and grade-size distribution of the Karewa suite*

[Figures indicate percentages, except those for the first quartile, median, and third quartile diameters, which represent microns.]

Formation	Tarrot		Lower Karewa					Upper Karewa						Potwar	
Specimen no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Main constituents:															
CaCO$_3$	67.93	91.20	...	23.77	39.16	11.40	...	...	27.95	15.60	77.53	71.87	19.73	18.70	19.38
Insoluble residue	32.07	8.80	100.0	76.23	60.84	88.60	100.00	100.00	72.05	84.40	22.47	28.13	80.27	81.30	80.62
Condensed mechanical analysis of insoluble residue:															
Sand	0.3	...	21.0	2.1	0.2	2.3	...	...	1.1	5.6	1.4	...	...	2.2	1.2
Coarse silt	33.7		25.4	25.5	37.1	64.0	16.7	15.0	22.0	49.1	54.3	13.6	40.4	60.9	43.3
Fine silt	41.1		29.3	53.5	43.1	23.5	53.5	46.7	66.8	34.3	32.2	61.7	41.0	26.9	42.2
Clay	21.8	...	23.0	17.1	20.6	10.2	28.8	35.5	10.9	10.9	11.9	24.8	18.4	11.0	13.2
Detailed mechanical analysis of insoluble residue:															
1. >0.5 mm	...	...	4.7		...	...	...	...	...	...	...	...	...	...	...
2. >0.25 mm	...	...	5.3		...	...	...		...	2.8	...	...	...	...	...
3. >0.14 mm	...		5.2	...	...	...	...	...	...	0.9	...	...	...	...	...
4. >0.074 mm	0.3	...	5.8	2.1	0.2	2.3	...	...	1.1	1.9	1.4	...	...	2.2	1.2
5. >0.035 mm	22.3		16.2	13.2	27.1	40.8	2.5	6.6	16.9	35.1	36.3	4.6	26.9	42.8	28.3
6. >0.020 mm	11.4		9.2	12.3	10.0	23.2	14.2	8.4	5.1	14.0	18.0	9.0	13.5	18.1	15.0
7. >0.010 mm	19.5		12.5	24.0	17.5	11.4	29.0	11.8	25.3	15.7	13.4	25.1	20.1	13.3	22.5
8. >0.005 mm	24.6		16.8	29.5	25.6	12.1	24.5	34.9	41.5	18.6	18.8	36.6	20.9	13.6	19.7
9. >0.002 mm	15.2	...	10.2	10.9	11.9	4.9	10.3	20.8	0.9	2.9	5.9	9.9	8.8	5.6	6.2
10. <0.002 mm	6.6		12.8	6.2	8.7	5.3	18.5	14.7	10.0	8.0	6.0	14.9	9.6	5.4	7.0
Detailed cumulative mechanical analysis of insoluble residue:															
a. >0.5 mm	...		4.7	...		...	...	...	...	...	...	...		...	...
b. >0.25 mm	...	...	10.0		...	...	...	...	...	2.8	...	...	...		...
c. >0.14 mm	...	...	15.2		...	...	...	...	...	3.7	...	...	...		...
d. >0.074 mm	0.3		21.0	2.1	0.2	2.3	...	...	1.1	5.6	1.4	...	...	2.2	1.2
e. >0.035 mm	22.6		37.2	15.3	27.3	43.1	2.5	6.6	18.0	40.7	37.7	4.6	26.9	45.0	29.5
f. >0.020 mm	34.0		46.4	27.6	37.3	66.3	16.7	15.0	23.1	54.7	55.7	13.6	40.4	63.1	44.5
g. >0.010 mm	53.5		58.9	51.6	54.8	77.7	45.7	26.8	48.4	70.4	69.1	38.7	60.5	76.4	67.0
h. >0.005 mm	78.1		75.7	81.1	80.4	89.8	70.2	61.7	89.9	89.0	87.9	75.3	81.4	90.0	86.7
i. >0.002 mm	93.3		85.9	92.0	92.3	94.7	80.5	82.5	90.8	91.9	93.8	85.2	90.2	95.6	92.9
k. <0.002 mm	99.9		98.7	98.2	100.0	100.0	99.0	97.2	100.0+	99.9	99.8	100.0+	99.8	100.0+	99.9
Significant grade-size characteristics:															
First quartile diameter	33		64	23	38	52	17	11	19	53	49	14½	37	53	42
Median diameter	11		17	10½	12½	27	9	6½	10	25	21	8	15	31	18
Third quartile diameter	5½	...	5	6	6	12	3½	3	7−	9	8½	5	6½	10½	8

Table 2.—*Graphic representation of the main petrographic and genetic characteristics of the Karewa suite*

FORMATION			TATROT		LOWER KAREWA					UPPER KAREWA						POTWAR	
Specimen No.			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
MINERAL COMPOSITION (Heavy minerals only from fraction > 0.05 mm)	Major light constituents	Quartz	≣	≣	≣	≣	≣	=	≣	≣	—	≣	≣	≣	≣	≣	≣
		Chert					=	≡							=		=
		Microcline	=		—	=	—	—	—	—	≡		=		=	=	=
		Plagioclase			—		—	—	—	—	≡	—	—			—	=
	Micas	Muscovite	=			=	≣	=			≣	=	≡		=	≣	≣
		Biotite	=				—	=		=	—		≣	=	—	≡	=
	Iron ores	Leucoxene–ilmenite	=		=	=	=	≡			=	=	=	=	=		=
		Magnetite											=		=		=
	Non-opaque heavy minerals	Actinolite										=					
		Anatase	=		=			=			=		=				
		Andalusite			=												
		Barite	=		=	≡	=	=								=	
		Chlorite	=		=	=	=	=	=		=	=	≡			=	=
		Chloritoid			=	=		=					=				
		Dolomite	=								=						
		Epidote			≡	=	=	=	=		=	≡			=	=	
		Fluorite	≡														
		Garnet	=		=	—	=		=					=	=	=	=
		Hornblende	≣		≡	=	=	=			=	=	—			=	=
		Kyanite			≡	≡	=				=	=		=		=	
		Rutile			=	=						=					
		Sillimanite					=					=	=			=	
		Staurolite						=			=	=	=			=	=
		Titanite	=												=		=
		Tourmaline		=	=	=			=			=	—	=		=	=
		Zircon	=		—	—	=					—					
		Zoisite				=		=	=								=
ORGANIC MATERIAL		Diatoms	=	≡			=	=	≡		=		?		—		?
		Pollen	=				=		=		=						=
		Shells of mollusks	—			≡						=					
		Other organic matter	≡	?	≡		=	≡	≡	—				—			
GENETIC FACTORS AFFECTING THE SEDIMENTS	Lithology of source area	Igneous	≡		=										?		
		Metamorphic	?		≣	≡	≡	≡	?		≡	≡	≣	=		—	?
		Normal sedimentary		≡	=	—	—		?					=	=	=	≡
		Red beds											—	=	=	≣	=
	Probable transport prior to deposition	Glacial	?					=	=	=					?		
		Eolian				=	=	=			—			—	≡	≡	≣
		Fluvial	=		=						≡	=	=	≡	?		
	Character of post-depositional alteration	Recrystallized calcite	—	=			—				=			—			
		Secondary calcite											=		=	=	=
		Authigenic barite	=		=	≡		=								—	
		Diagenesis + alteration				=	—	—					≡		≡		
		Pre-recent weathering				=	—	=		—	—				≡		=

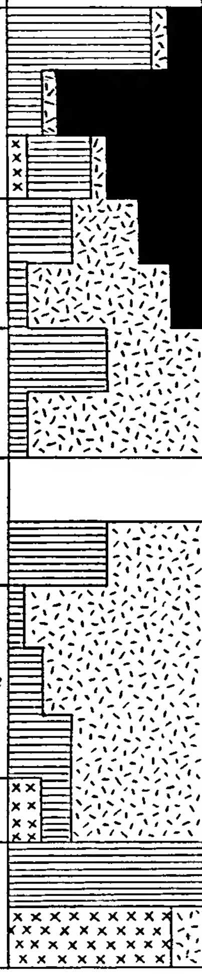
Explanation of symbols:

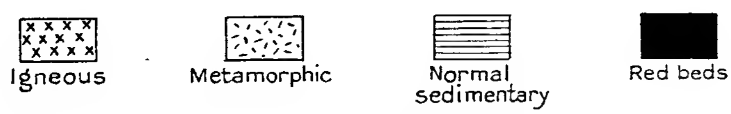
≣ Very abundant quantitatively or strongly predominant in character.
≡ Abundant quantitatively or dominant in character.
= Present quantitatively or existent in character.
— Rare quantitatively or subordinate in character.
? Dubious.

Note: Symbols indicate relative abundance or prominence within the following subdivisons: (1) major constituents, iron ores, and micas; (2) heavy minerals; (3) organic material; (4) the three types of genetic factors.

TABLE 3.—*Relation between stratigraphic position and genetic and petrographic characteristics of the Karewa suite*

Formation	Horizon	Specimen No.	$CaCO_3$ content	Relative lithology of source area	Type of predepositional transport	Type of deposition
POTWAR		15				Subaerial (eolian and pluvial loess)
		14	19%			
UPPER KAREWA	Zone 4	13			Eolian	
	Zone 3	12	High			
	Zone 3	11				
	Zone 2	10	Moderate		Fluvial	
	Zone 2	9				
	Zone 2	8	None			Lacustrine
LOWER KAREWA	Zone 4	7			Glacial	
	Zone 4	6				
	Zone 3	5	Moderate		Eolian and partly fluvial	
	Zone 2	4				
	Zone 2	3	None		Fluvial	Paludal
TATROT		2	High		?	Lacustrine
		1			Torrential	





NOTE.—The Karewa zones are defined on pages 110–113.

PART II. PLEISTOCENE GEOLOGY AND STONE AGE CULTURES IN NORTHWEST AND PENINSULAR INDIA

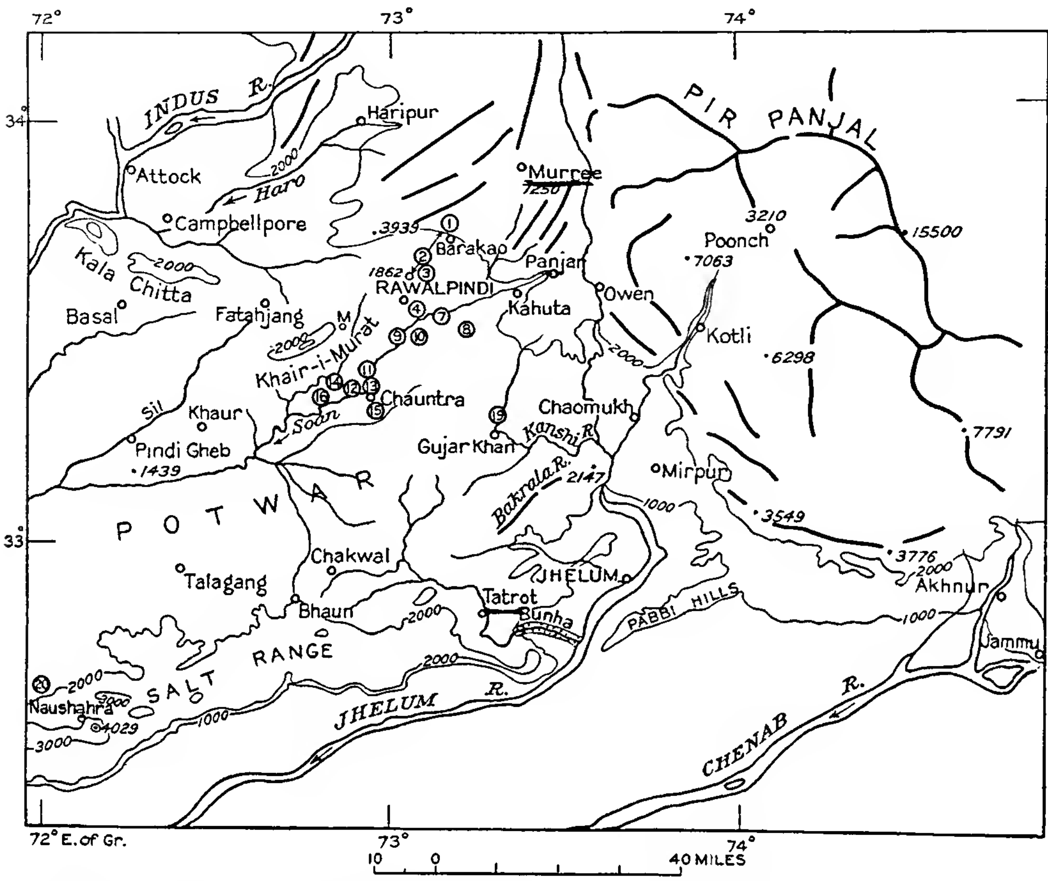


FIGURE 152.—Map of the region between the Jhelum and Indus rivers in northwestern Punjab. Numbers in circles refer to geologic sections described in text.

A. OUTLINE OF THE UPPER SIWALIK AND YOUNGER PLEISTOCENE HISTORY OF THE POTWAR REGION

The Potwar region embraces an elevated portion of the plains in northwestern India (fig. 152). Lying between the foothills of the Kashmir Himalaya and the Salt Range, its 7,000 square miles of undulating land stretches from the Indus to the Jhelum River. Physiographically the Potwar marks the border of the Indo-Gangetic plains province, but its geologic position is characterized by the close proximity of the mobile Himalayan belt to the northern rim of the Indian land mass, of which the Salt Range is an advanced outpost. Nowhere but here can one view the snow-capped Himalaya from the mountain slope of peninsular India. This position accounts for most of the physiographic and geologic peculiarities, and it explains, to a certain extent, the long range of the archeologic records. For hereabouts lay the northern limit to which prehistoric migrations advanced from the south, and here also was the promised land of the foreign conquerors—

the fertile river tracts to which they descended after arduous trekking across the highlands of India's northwestern borderland.

To understand the geologic history and prehistoric records of the Potwar, it is first essential to outline the major geologic events which characterized the end of the Pliocene period. This is of special importance, in view of the puzzling variety of geologic records of the Quaternary period, most of which were dependent on the heritage of preceding times. The following table gives the stratigraphic sequences for this region according to earlier sources. In this, the age interpretation is modified as compared with the dating adopted by the Geological Survey of India.

Siwalik sequence in Punjab, giving comparative estimates of thickness in feet (see fig. 153)

	Wadia (1928)	Cotter (1933)	Van Vleck-Anderson (1927)	Pilgrim (1910)	Wynne (1877)
Pleistocene:					
Middle:					
Boulder conglomerate (coarse gravel and sand)					
Lower:	6,000		4,500–9,000	5,000–6,000 (Malakpur)	3,600–5,000
Pinjor zone (pink silt and sandstone).		2,000			
Tatrot zone (conglomerate, gray sandstone, and silt)					
		break			
Pliocene:					
Upper (?).					
Middle:		2,000–2,100			
Dhok Pathan zone (orange and pink sandstone and shales) . . .	4,500	2,460 (Bhaun)	5,000–6,000 (Soan)	1,300 (Salt Range)	
Nagri zone (pepper-colored sandstone and red shales)					
Lower:					
Chinji zone (orange-brown and brick-red sandstone and shales) . . .	3,600	4,000 (Khaur)	1,400–2,800 (Jatla)	1,500	
Miocene:					
Upper:					
Kamlial zone (hard red and gray sandstone and shales)	1,350	900 (Khaur)	900–2,000	1,000	
Murree series (purplish-red and maroon sandstone and shales) .		?5,000	5,000–8,000	8,000	7,500–8,000

THE POTWAR AT THE END OF THE TERTIARY PERIOD

PLIOCENE-PLEISTOCENE BOUNDARY

In trying to analyze the geologic composition and ancient relief which this country had at the beginning of the Ice Age, it is necessary to give our definition of the Pliocene-Pleistocene boundary. In a previous paper (De Terra and Teilhard, 1936) we have already presented evidence which shows that there is a marked dividing line between the Pliocene Middle Siwalik and the Pleistocene Upper Siwalik beds which underlie most of our territory. This is a disconformity, or at many places, as Pilgrim (1910, p. 192) has already stated, an angular unconformity which separates the thick masses of sandstones, clays, and conglomerates

of both groups. Though it is often not easy, at first sight, to distinguish the Upper from the Middle Siwaliks, it is nevertheless true that the latter are more cemented and more varied in color than the younger beds. In the Soan Valley the upper Dhok Pathan beds are composed of hard, coarse conglomerates and gray to reddish sandstones, and where these are missing tough reddish clays and siltstones usually underlie the basal Upper Siwalik conglomeratic sandstones. These are usually of looser consistency than those found in the Dhok Pathan zone, and the overlying pink clays are also less consolidated. A complete section, such as is found in the

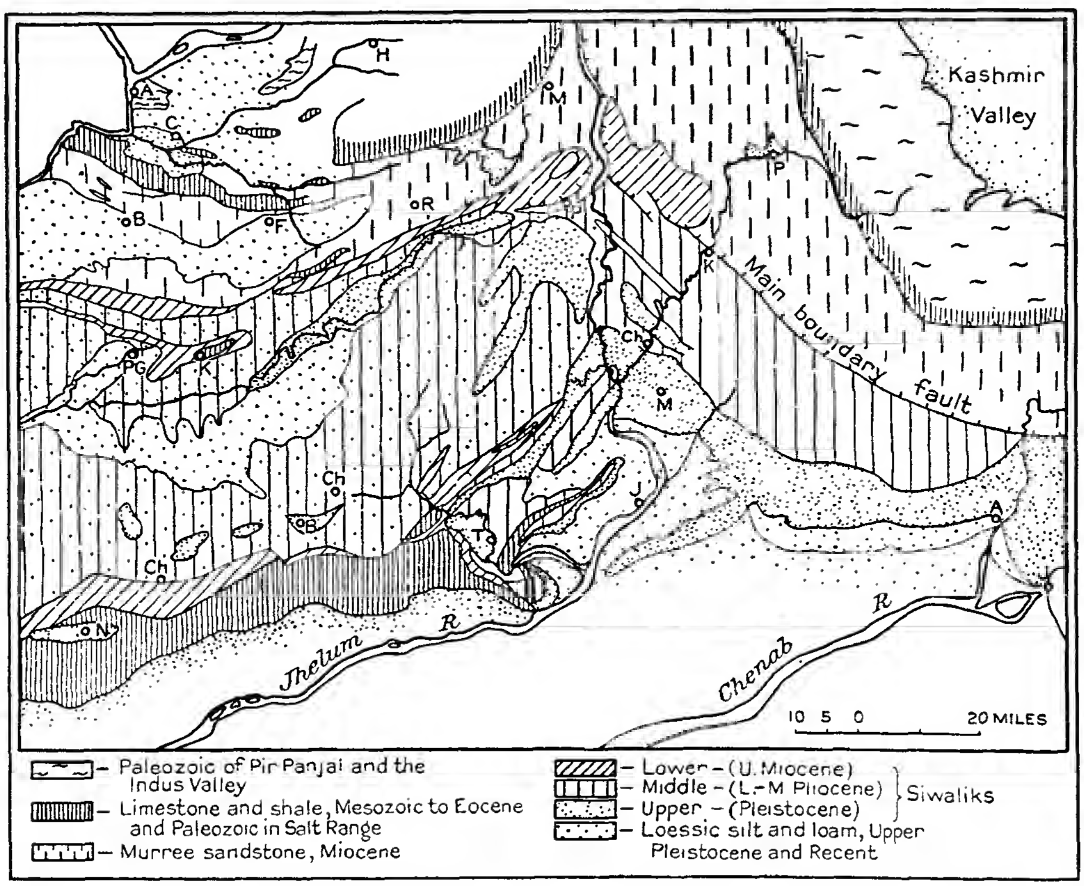


FIGURE 153.—Geologic sketch map of the Potwar area. Letters stand for localities shown on figures 152 and 154.

Soan Valley near Chauntra, or on the northern slope of the Salt Range at Bhaun (see Cotter, 1933), does not fail to bring out clearly the two groups, in regard to both color and lithologic composition. At all places the so-called Tatrot zone marks the beginning of a new cycle of sedimentation recorded by basal conglomerates or gravelly sandstones in which are found the rewashed components of older beds and, in places, of older fossils. Such conditions have been described in detail from various localities in the Potwar and neighboring regions, and we need not further emphasize this situation, which is accepted by those geologists to whose painstaking surveys we owe the geology of the Potwar.

When it comes to paleontologic records, opinion as to what constitutes the formational boundary in question is less unanimous. Pilgrim (1913, 1934) regards the Upper Siwalik beds as of Pliocene age, except for the Boulder conglomerate, which he referred to the lower Pleistocene. Matthew (1926) and Colbert (1935), however, are insistent on the Pleistocene character of the Tatrot-Pinjor fauna which occurs throughout the bulk of the Upper Siwalik sequence below the upper conglomerate. Following Matthew, Colbert says: "The Middle Siwalik fauna represents the holdover of a typically Pontian group of mammals into the middle of the Pliocene, or at least into post-Pontian times." Regarding the Upper Siwaliks, both of these paleontologists agree that the presence of *Equus* in these beds shows that they are of Pleistocene, "very probably of lower Pleistocene age" (Colbert, 1935, p. 23). This view has recently been adopted by Teilhard de Chardin (1937), and from Hopwood's writings (1935), it is evident that he also regards the appearance of new intruding faunistic elements such as *Equus*, *Bos*, and *Elephas* as the beginning of the Pleistocene in Eurasia and Africa. In general, there has been of late a strong tendency among paleontologists to follow Haug's definition of the Pleistocene (1911). Whatever its shortcomings may be, it seems nevertheless practical, for many reasons, to adopt this definition in our case. In this way it may be possible to correlate our Pleistocene records with those of other regions and to elucidate thereby the age problem of early man. As has already been shown, the Pliocene-Pleistocene boundary in the Siwalik region of the Potwar coincides with the disconformity between Middle and Upper Siwalik beds. Does this sedimentary break represent a long hiatus, or is the disconformity just a brief interval which initiated a new cycle of erosion? For the following reasons we are inclined to think that the first assumption is better justified.

Wherever the basal Upper Siwalik beds are studied in the isoclinal belt of the Potwar, we encounter the Tatrot and Pinjor zones, either in individual basins, as at Campbellpore and Kahuta or in the central Salt Range, or in synclinal valleys, as along the Soan River, where they unconformably overlie the slopes of a planed elevated surface (fig. 154). These depressions are primarily of structural origin, because of their intermediate position between anticlines (fig. 153) or because of the faulted nature of the basins. At Campbellpore, for instance, they rest against the buried fault scarp of the Kala Chitta ridge, and in the Salt Range at Naushahra they fill a faulted intermontane basin. (See De Terra and Teilhard, 1936.) The formation of these basins must have embraced a considerable period of uplift, faulting, and erosion, if we consider that at that time the older Siwaliks covered practically all the elevated portions of the anticlinal ridges, which now surmount the Potwar by 1,000 to 2,000 feet (fig. 152, pl. XXV, 4). At Naushahra (Punjab) and near Tatrot it became clear (De Terra and Teilhard, 1936) that the preceding uplift had initiated a new slope drainage which resulted in the deposition of coarse detritus, composed of Paleozoic, Mesozoic, and older Tertiary rock débris. This composition reflects the breaking up of the older relief into smaller basins and indicates, generally speaking, that the monotonous foreland sedimentation which had prevailed since Miocene time had ceased. From Tatrot time on, the rivers depos-

ited their loads not on a sloping alluvial plain but in basins or valleys that followed the northeast-southwest strike of the newly formed fold pattern. This change is evident, not only from the sedimentary record, but more visibly so from the present-day topography.

Potwar Peneplain

A large portion of the Potwar region exhibits a wide expanse between the intermediate ridges, beveling the upturned strata of Tertiary beds (fig. 154). In the Soan tract, downstream from Chauntra, this level is beautifully preserved at the place where it cuts across Dhok Pathan beds (pl. XXV, 1). Southwest of the Khair-i-Murat ridge it extends as an undulating flat surface from the Salt Range slope clear across the Soan to the Kala Chitta, a stretch of 50 miles. Unconsumed ridges of resistant Siwalik sandstones, which nowadays protrude from the Kamlial-Nagri and Dhok Pathan zones, and broad depressions must have given this surface, originally, an undulating relief, which was subsequently greatly dissected and altered by erosional and depositional processes. The total relief of this land surface fluctuated within a few hundred feet. The effects of this widespread planation are visible also in the now elevated intermediate ridges. In the Kala Chitta, for instance, 6 miles distant from its southern slope, north of Basal, a late mature relief is found with broad terraced strike valleys filled with weathered boulder débris of Mesozoic and Cenozoic formations. The ancient valley floors here lie 800 to 1,000 feet above the planed surface of the southern slope. The fault escarpments on this flank are dissected by subsequent streams, which have not yet succeeded in capturing the longitudinal drainage channels in the central portions of the ridge. Similarly, the flanks of the Khair-i-Murat show traces of this mature relief in the form of high leveled spurs which extend for a few miles into the ancient planed level. Presumably, these spurs were derived from dissection and uplift of pediments which developed during the peneplanation period in late Pliocene time. Such level spurs are found west of Murat village, where they surmount the peneplain by 230 feet (fig. 155, pl. XXV, 4). Like the peneplain, these spurs are underlain by Murree sandstone and shale, but in contrast to the Potwar level, they are covered by angular, coarse limestone débris, derived from the Nummulitic of the Khair-i-Murat ridge (fig. 156). This fanglomerate is restricted to the spurs and is not more than 30 to 40 feet thick. It is an old fan deposit which covered the pediment before uplift and faulting took place. Beyond the border fault high mature valleys are visible in the range remnants of this old relief, indicating the prolonged period of peneplanation which befell both the folded Siwalik beds and the intermediate anticlinal ridges. As these ridges are generally built of more resistant rocks, such as massive Nummulite limestone which had undergone uplift and fault thrusting, it is obvious that their pre-Pleistocene relief was higher and more varied than that of the intermediate lower regions.

The planing agency to which this leveling was due is to be looked for in a drainage system of late Dhok Pathan and pre-Tatrot time. Then the isoclinal folding, presumably, had not yet reached its present expression; the folds were

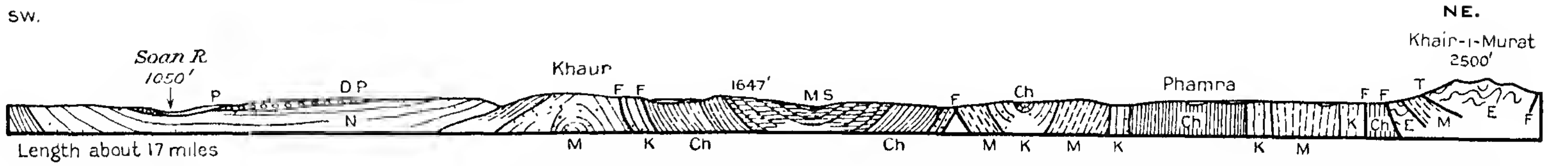


FIGURE 154.—Cross section through Potwar between Khair-i-Murat ridge and Soan Valley. E, Eocene; M, Murree sandstone; K, Kamlial sandstone; Ch, Chinji zone; N, Nagri sandstone; D.P., Dhok Pathan zone; M.S., Middle Siwaliks generally; P, Potwar loess; T, thrust fault; F, fault. (After Cotter.)

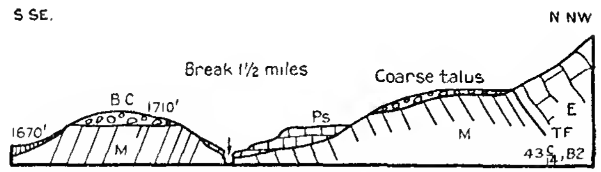


FIGURE 155.—Transverse section through fault escarpment of Khair-i-Murat west of Murat. B.C., Boulder conglomerate; Ps, Potwar silt; M, Murree series; E, Eocene; TF, thrust fault.

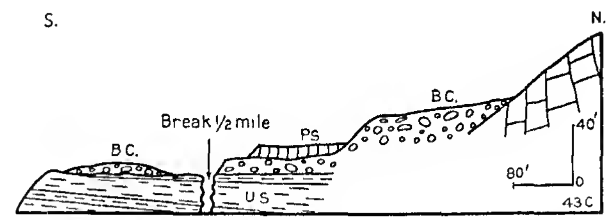


FIGURE 156.—Schematic section through valley fill and adjoining slope of Kala Chitta near Hatar, Fatahjang Tahsil. B.C., Boulder conglomerate; Ps, Potwar silt; U.S., brown laminated silt and sand.

shallower and the ridges lower, with the rivers meandering leisurely across the land, planing whatever relief the folding had formed. These rivers, however, could not have been the same as those which flow now in the Potwar region, for their size is wholly insufficient for so extensive an erosion as the peneplanation demands. We rather think that it was a major slope stream, such as the Jhelum, which now erodes a wide floor northwest of the Pabbi Hills anticline (fig. 153). This river probably once discharged part of its turbulent mountain waters through a water gap near Panjar, northeast of Kahuta. (See p. 280.) Indeed, the behavior of this stream at the mountain border provides, possibly, a sort of "leitmotif" for the Pleistocene history of the Potwar region. Figure 157 shows how the Jhelum approaches its outlet at Owen, in a valley which is deeply incised between two major faults. About 4 miles above Owen it receives a small stream from the region of

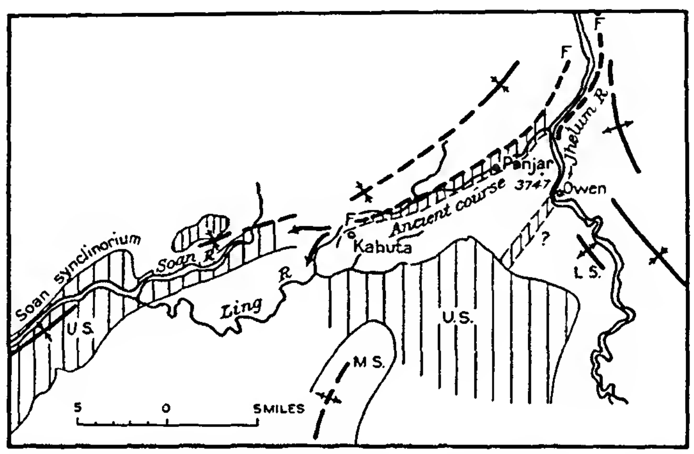


FIGURE 157.—Sketch map of Jhelum River outlet and upper Soan drainage in relation to structure. U.S., Upper Siwalik; M.S., Middle Siwalik; L.S., Lower Siwalik; F, fault.

Panjar. The confluence points upstream, the tributary making an acute angle with the master stream in reversed order. This rivulet drains a valley that forms a broad depression in faulted Kamlial rocks, and it continues for twelve miles to Kahuta, where it has an outlet into the Potwar. This valley has a low watershed separating the Jhelum and Soan tributary drainage areas. A few miles west of Kahuta begins the Pleistocene filling of the Soan synclinorium, and southeast of this place the Upper Siwalik beds assume great thickness. Now, at a time when the Jhelum flowed on a higher level and the Potwar plain extended to Kahuta, the Jhelum would normally have followed the first southwest-striking fault line, rather than traversing the then unquestionably higher and more resistant ground above Owen. As its major bend here followed, faithfully, the strike of the faults, it is only logical that it should have pursued its course in a manner similar to that which led the ancestral river into the Soan depression. This means that the Potwar region must have been planed by this ancestral stream, which was presumably braided in the tradition of the Siwalik streams. Thus many meandering channels

may have occupied the depression between the Salt Range and the Khair-i-Murat, leveling the relief of the late Middle Siwalik stage. As shown in a later chapter, the Jhelum changed its course to the present position in middle Pleistocene time.

The time period during which the Potwar peneplain developed evidently is fixed by the relative ages of the Dhok Pathan and Tatrot rocks. The former, being the last zone involved in the process of planation, has been determined as lower Pliocene by Pilgrim (1910, 1913) and of Pontian age. Matthew (1926), however, showed that the Dhok Pathan fauna, especially the horses and Giraffidae, are more advanced and specialized than any of the Pontian forms found at Pikermi, Samos, or in China. He therefore considered the Dhok Pathan zone as representing the middle Pliocene. This view has lately been adopted by Lewis (1937, p. 199), who pointed out, first, that the upper Pliocene in the Siwalik series is recorded neither by a fauna nor by sediments but by a period of prolonged erosion; and second, that the Dhok Pathan, as Matthew stated, is of middle Pliocene and the Tatrot zone of early Pleistocene age. Hence, it would appear that between the Middle and Upper Siwalik groups there is a long hiatus, which embraces upper Pliocene and perhaps even middle Pliocene times. The paleontologic evidence for this stratigraphic scheme is corroborated by our physiographic study of the Potwar region. The peneplain must certainly have required a long period of erosion, during which the Siwalik folds were beveled, subsequent to shallow folding. If the Dhok Pathan were of upper Pliocene age it would be difficult, or even impossible, to account for the Potwar peneplain, because a brief hiatus, between upper Pliocene and early Pleistocene time, would be insufficient.

In late Pliocene time, then, our region presented an undulating planed surface, the relief of which was broken up into several shallow depressions, such as the Soan syncline, which was drained by an ancestral Jhelum River. The Khair-i-Murat ridge then formed an important divide between the Jhelum and Indus rivers (fig. 152). One of the Indus tributaries, the Haro River, still receives from the Khair-i-Murat a long side stream called Nandna Kas, which crosses the eastern Kala Chitta in a deep valley. This stream behavior can be explained only by antecedence, as the headwater pattern of the Nandna Kas lacks any signs of stream capture. In other words, the Kala Chitta then terminated farther west as a ridge, permitting the Indus tributaries to drain the western Potwar.

At the end of the Pliocene period, just prior to the deposition of the Tatrot sediments, uplift occurred, resulting in dissection of the high regions bordering the Potwar plains. Both the lithology of the basal Tatrot beds and the general distribution of the Upper Siwalik beds testify to such an event. Where the older Upper Siwaliks are preserved on the Salt Range slope (Tatrot, Bhaun) they are composed of detritus derived from newly exposed rocks (Cotter, 1933; De Terra and Teilhard, 1936). Also, the Upper Siwalik beds occur nowadays in basins or along stream channels, and are not found on the Potwar peneplain proper, though they constitute an important element on the flanks of anticlines (Bakrala, Salt Range, Kala Chitta). In many places they gently overlap underlying Middle Siwalik beds, indicating that here the Potwar had a low undulating relief.

UPPER SIWALIK PERIOD

Tatrot Stage

Wherever Tatrot rocks overlie the Middle Siwalik beds, a basal conglomerate or conglomerate sandstone of gray or brown color is found. On the northern Salt Range slope at Bhaun it is 100 feet thick (Cotter, 1933, p. 122); on the southern flank at Jalalpur the break with older Siwalik beds is conspicuously recorded by a thick series of conglomeratic sandstones lying directly on Lower Siwaliks. Hence, Pilgrim (1913, p. 275) concluded that the Middle Siwalik beds, measuring presumably over 1,000 feet, were denuded before the Tatrot sandstones were laid down. He reported a similar unconformity from the Bakrala anticline, and we have previously (De Terra and Teilhard, 1936) presented evidence for a similar break in the upper Soan Valley and at other places. However, it would be incorrect to say that the formational boundary is always unconformable.[1] Wherever the Dhok Pathan beds presented an even dip slope, as in the less compressed portion of the Soan syncline near Gila Kalan, Tatrot sandstones overlap evenly, but in such places one generally notices a different pebble composition or a lesser degree of hardness in the basal beds as compared with the Dhok Pathan. Wadia (1928, p. 343) observed that the dip becomes flatter and the strike more changeable in Upper Siwalik rocks, indicating the greater degree of consolidation by folding and age in the older Siwaliks.

The Tatrot zone was everywhere found to be composed of coarse, usually soft sandstones with conglomerate bands and brown silt layers interspersed. Delta structure on a large scale prevails, and lateral changes in facies are common. It is this sedimentary complex for which we retain the name "Tatrot," representing a stage of quick river deposition and filling of preexisting lowlands in the Potwar plains. It is evident that such rapid accumulation of almost 1,000 feet of sandrock must have required powerful streams and abundant rainfall. In addition there must have occurred rejuvenation of stream patterns in the elevated tracts, especially in the Salt Range and in the Pir Panjal. As has been pointed out elsewhere (p. 30), the Pir Panjal was in a state of uplift and dissection when the first glaciation set in, and obviously the southern slope streams, such as the Jhelum, transported great loads of débris into the plains. Also, in the Potwar, denudation proceeded more rapidly than before; Siwalik and older rocks are found as pebbles in the Tatrot sandstone. In some places, as at Tatrot, even fossilized bones of mammals were washed out of the Dhok Pathan zone and re-embedded in basal conglomerates.

The Tatrot stage was in fact the sedimentary precipitate of a process dominated by uplift of the surrounding highlands and promoted by moist climatic conditions. In this respect it is important to note the absence of any red beds such as characterize the older Siwalik deposits. Also, the prevalence of fossil remains of elephants, pigs, hippopotami, bovids, turtles, and crocodiles very strongly indicates a moist climate and abundant vegetation. At some places, as

[1] See Paterson's notes on the Poonch Valley, especially his studies on the Kotli syncline (fig. 133).

at Tatrot, the basal beds carry large quantities of gray and dark jasper and flinty pebbles, the peculiar angular shape of which led one of our fossil collectors in 1935 to suspect human workmanship. Upon closer examination, however, it was found that these pebbles owe their shape to weathering agencies, thermal fracture, and wind corrosion, which probably preceded their ultimate deposition. There are, in fact, no indications that the river beds of the Tatrot epoch were ever exposed for any length of time, and hence whatever soils and associated diagenetic processes might have developed, their effects were rapidly destroyed or buried by shifting sands. Quite possibly the elevated tracts of the central Salt Range experienced frost action, as is indicated by the petrologic analysis of Krynine (p. 239). The sample on which this supposition is based came from a brown silt in the basal Upper Siwalik beds of the Naushahra Basin in the Salt Range. A clay sample from this locality was found to contain many diatoms. Mr. Conger listed the following:

Sample 22. Naushahra, India. Fresh-water clay (Tatrot stage, early Pleistocene). Light-colored medium-hard rock; much lime. Many sponge spicules; diatoms frequent, as follows:

Cyclotella kützingii Thw.	C
Cymbella ventricosa Ktz.	F
Epithemia sorex Ktz.	S
Gomphonema intricatum Ktz.	C
Mastogloia elliptica Agardh	C

For explanation of letters see page 120.

(The last two forms dominate the sample, as to diatoms.)

Although it is probable that the relief of the Potwar was somewhat accentuated in pre-Tatrot time, it is, in view of the great thickness of these beds, nevertheless necessary to assume a pari passu sinking of the major depressions. Such a process is plausible, if we consider that the rivers followed synclines or flowed through basins of structural origin, such as the Soan and Tatrot regions (fig. 153). The uplift of the adjoining Himalayan fold belt and of the Salt Range anticlinorium must have led to further compression and deepening of the intermediate tracts which had previously shown similar tendencies.

Pinjor Stage

De Terra and Teilhard (1936) have lately pointed out that from a paleontologist's viewpoint it appeared advisable to consider the Tatrot and Pinjor zones as represented by a more or less uniform fauna and by one great cycle of sedimentation. Also, the gradual sedimentary passage between these zones made the division of the early Pleistocene into two units rather arbitrary. This view was adopted by Lewis (1937), who proposed to eliminate the Pinjor zone altogether by calling the beds of the Upper Siwaliks older than the Boulder conglomerate the "Tatrot zone." Weighty as these arguments are, it seems for our purpose advisable to retain Pilgrim's stratigraphy and to differentiate among three Upper Siwalik units for the following reasons. The so-called Tatrot zone is made up of gray or

brown sandrock and conglomerate, whereas the overlying unit consists of pink or variegated silts and sands. This lithologic difference is significant, in view of an analogous succession in Kashmir, where two distinct zones, the first glacial and first interglacial, indicate a fluvial fan and a lacustrine stage. This analogy is so obvious as to induce us to visualize two separate stages, not clearly expressed by the fauna, each of which required special geologic conditions. These conditions seem to be partly of a structural and partly of a climatic nature, as is made evident in the following discussion of Pinjor beds. These geologic distinctions even seem to be reflected in the fossil records, for it is known that most of the Upper Siwalik fossils were collected in pink clays and sands below the Boulder conglomerate. Colbert's list of Siwalik mammalian remains (1935) reveals the scarcity of fossils in the Tatrot zone and their abundance in Pinjor beds. Future paleontologic studies may show that these differences are not merely numerical but connected with a slight change of fauna.

The Pinjor zone consists of a series of pink or brown silt and sand with gray, mauve, and drab beds intercalated. The latter are prominent in the section at Bhaun, as described by Cotter (1933) and by us (De Terra and Teilhard, 1936). There, according to our measurements, they are at least 900 feet thick, while in the Soan Valley they may not amount to more than half that much. In all sections these beds lie conformably on the Tatrot zone, from which they develop gradually, the gray sandstones of Tatrot age being replaced by pink sand and silt. Outside of the Potwar, in the Pabbi Hills, this zone is 500 feet thick, and in the foothills, at Jammu, it measures close to 1,500 feet. In Poonch, also, the thickness exceeds that found in the Potwar and Salt Range sections, indicating a progressive thickening toward the mountain front. These estimates are based on the assumption that the Pinjor zone begins with the first thick band of pink silt above the upper Tatrot coarse sandrock, and that it terminates with the first coarse conglomerate layer above the silt. In the upper Soan region only banded or laminated silt and clay of warm red tint are represented, but in the middle tract, near Chauntra, pink and brown sand appears beneath the red silt.

Two features distinguish these beds from the other two Upper Siwalik zones—the dominance of pink silt and the even banding and lamination. The latter is beautifully exposed at Adial, in the Soan Valley, where individual layers measure 5 to 10 feet in thickness. Also, wherever the lower variegated portion is encountered, as in the northern flank of the Pabbi Hills, stratification is very even over several miles. There are, however, differences in facies between various regions and lateral passages from silt to sand, suggestive of shifting stream channels. It is as if the rivers of Pinjor time had grown sluggish, meandering freely across wide flood plains that extended beyond the limits adhered to by the Tatrot drainage. This may have led to temporary ponding and deposition of laminated silt. On the other hand, as discussed below, the rhythmic banding found over extended areas suggests some sort of agency which regulated the sedimentary supply.

The change from gray pebbly river sands of Tatrot age to reddish silt and variegated fine sands is similar to that found in Kashmir, where the pre-Karewa

fans are overlain by the Lower Karewa lake beds. As the Pinjor drainage was presumably the same as in Tatrot time, it is obvious that the slope streams ultimately must have attained a more even gradient. This was promoted by the relative crustal stability of their source area in Kashmir, where we had previously reported quiet-water deposition (Lower Karewas). This picture of a graded drainage in the plains is in accord with the sedimentary composition of the Pinjor zone, but it makes it somewhat difficult to account for the great thickness of this zone, for it must be recalled that the Potwar relief was flat, and that the major depressions had already been filled with Tatrot beds. Also, the supply of silt was probably restricted to those stream channels which had managed to cut through silt-bearing older Siwalik formations. On the other hand, the tectonic pattern of the area suggests that depressions, such as the Soan tract, continued their sinking tendencies, thereby allowing the streams to add more sediment to the previously existing channels. In regard to the sedimentary supply, it would seem that the rivers carried an initial load of silt from the mountains, where glacial deposits furnished limited quantities of loose silt and clay matter. However, in view of the greater thickness of the Pinjor zone in the foothill region, it is necessary to assume that silt was here even more heavily accumulated than in the plains. We believe that this phenomenon can be explained most satisfactorily by eolian drift. The petrologic analysis of the Pinjor silt from the Soan region, as worked out by Krynine (p. 247), shows that we have to deal with loessic material. Its source area is to be looked for mostly in the red siltstones and sands of older Siwalik formations and partly in such as-yet-undenuded soils, periglacial as well as glacial, as were picked up by the prevailing wind currents. It was shown previously that the monsoon must have swept across Kashmir during the first interglacial stage; in fact, its reign in this area was, presumably, greater than nowadays. This means that annually cyclonic conditions prevailed at the border of mountains and plains, just as the present-day arrival of the rainy season is heralded by violent winds and dust storms. The meteorologic charts reveal this clearly, and from personal observations from April to June and again in the early winter I can say that great quantities of silt are kept in suspension until the monsoon rains break. This process has previously been described by me (De Terra and Teilhard, 1936, p. 815) in explaining the nature of the Potwar loess of post-Siwalik age. The wide valley floors of Pinjor time unquestionably provided, between rainy seasons, large areas covered with loose silt; and as the strongest winds blew from the plains toward the mountains, large quantities of suspended matter drifted over the Pir Panjal into Kashmir. Part of this dust precipitated over the Kashmir Lake, where it was incorporated in the Lower Karewa lake beds; but in the south it settled in valleys and foothills, from which the rivers redistributed it. This process is still going on, though in a lesser degree, and presumably it prevailed with varying intensities during Pleistocene time. Accordingly, the Pinjor beds consist of both wind-blown and fluvial silt and sand; the rivers distributed not only slope wash and soils but great masses of dust, which annually settled over the region. It cannot be stated offhand that it was the monsoon rhythm which dictated sedimentation, because the individual layers are too

thick to represent annual deposits. But, just as the present precipitation varies, it is possible that during Pinjor time rainier periods alternated with drier intervals. Indeed, the presence of dark carbonaceous layers in the red silt, as mentioned by Wynne (1877, p. 122), is very suggestive of fossil soils developed during drier intervals.

The climate of this stage has already been characterized as a warm temperate one which promoted forest growth in Kashmir and rich vegetation in the plains, as the wealth of the Pinjor fauna indicates. It cannot be mere coincidence that, in this stage, the most typical Siwalik character is attained for the last time, as exemplified by the richness of mammal life and the prevalence of reddish-colored beds. Of all three Upper Siwalik zones, the Pinjor resembles most closely the older Siwalik, the difference being one of quantity rather than quality. The fauna appears to be of early Pleistocene age, and in it there are no records of such forms of life as require a tropical habitat, as anthropoids do. The red color, being one of derivation rather than of autogene origin, does not necessarily mean that the climate was warm-humid; at best it was subtropical, like northern central India nowadays.

Boulder Conglomerate Stage

Although there are no signs of any intense earth movements in the previous zone, yet the formational boundary demands a sudden diastrophic revival shortly before the great fans of the Boulder conglomerate stage began to accumulate. This boundary was defined as an angular unconformity wherever the Pinjor-Tatrot beds had been disturbed; otherwise it was pictured as a disconformity of erosional origin for regions where "deposition took place during subsidence previously begun in synclines" (De Terra and Teilhard, 1936, p. 818). We may add that the latter definition also covers the valley outlets in the foothills, where large streams built up another fan on top of older Upper Siwalik beds. (See p. 186.) For thrust faulting was reported from Kashmir and Jammu, where, at Udhampur, the older Siwalik beds were faulted prior to the fan formation. Similarly, at Kahuta, De Terra and Teilhard observed basin faulting of Tatrot-Pinjor beds, antedating the Boulder conglomerate. (See also fig. 133.) In the Soan Valley the contact is conformable and not everywhere easily defined, but upon closer examination it always proved to be a disconformity. Individual basins, such as those at Campbellpore, Kahuta, and Naushahra (Salt Range), subsided through faulting, which was accompanied by folding of Tatrot-Pinjor beds. In such places the Boulder conglomerate covers the earlier structure with massive and coarse débris (pl. XXVI, 2). This first infra-Pleistocene disturbance caused not so much a break-up of the planed land surface as a veritable deluge of coarse river alluvium, which the slope streams spread over the plains. Naturally the most active fold belt, the Pir Panjal, experienced the most severe denudation, for here both uplift and glaciation combined to break down the newly formed relief and structures. The Jhelum, Poonch, and Chenab rivers and numerous smaller streams piled up large fans, which are all over 1,500 feet thick and charged with boulders. On the other hand, the Potwar ridges were uplifted and dissected, as is clearly indicated

by the large fans on the northern slope of the Kala Chitta and by the limestone detritus of the Salt Range basins and valleys, all reflecting a high relief on the anticlinal ridges. From these slope streams fans accumulated, thinner than in the foothills and of different composition but essentially of analogous structure. In addition, the tributaries and smaller rivers descending from the Murree Hills carried bouldery gravel into the Soan tract, in which sedimentation continued, more rapidly but at first in much the same way as in the previous stage. In fact, the pink sands and alternating conglomerate layers of the Soan Valley pass rather gradually from the Pinjor silts, from which they are distinguished by coarseness of grain and more variable composition. Hence we can differentiate three major facies in the Boulder conglomerate.

1. Fan gravel: Loose pink sands and bouldery gravel with brown patination, 1,500 to 3,000 feet thick, as fans of major Himalayan slope streams and composed of crystalline and sedimentary rocks of all ages. Locally with erratics and faceted débris of second glacial derivation. Best exposed at Mirpur, in Poonch, and at Kotli.

2. Ridge gravels: Coarse, locally bouldery, somewhat cemented conglomerates and pink grit, 100 to 1,000 feet thick, as fans or valley fill of Potwar or Salt Range streams and composed mainly of limestone pebbles or Murree sandstone. Giving rise to hummocky ridges in Potwar region or to elevated terrace gravels on higher ground. Typically developed west of Campbellpore on Kala Chitta slope, along Khair-i-Murat and Salt Range.

3. Plains gravel and sand: Pink or gray grit with conglomerate and silt layers intercalated, restricted to synclinal channels, such as Soan, with thickness not exceeding 500 feet. Ridge-forming and locally merging with ridge gravel. Represented in Soan tract, especially near Rawalpindi.

This classification of the Boulder conglomerate must obviously be somewhat artificial, as the boulder fans and ridge gravels both merge into the river drift in the depressions. Nevertheless, the three facies can generally be distinguished, but in each locality it is imperative to establish their relation to each other, as this method alone will disclose their geologic position. It might be argued that it will be difficult, if not impossible, to prove that these facies are of the same age, especially at localities where no contact with earlier Siwalik beds is found. In such localities the relation with younger beds, especially with the Potwar zone (silt), will help to diagnose one of the facies. Also, their tilted status and the general unconformity above older Siwalik beds determine their age, as the sections to be described presently will show. In the absence of fossils it was important to observe that the specimens of the pre-Soan industry, coarse flakes or flaked pebbles, occur in the upper layers of the fan and plains gravel but nowhere in younger formations. The scarcity of implements in these deposits somewhat impairs their value for stratigraphic correlations, but with further collecting it should be possible to use this oldest industry as guide fossils for the three facies.

The sedimentary nature of the Boulder conglomerate in this area reveals the following characteristics:

1. Increase of coarse components in upper layers, with boulders and erratics most abundant. Pebble size 2 to 4 inches in the plains, increasing to 6 to 10 inches in the fans along the foothills.

2. Thickening of all fans toward elevated tracts and in major depressions such as Soan. Maximum thickness is encountered in the fan gravels of the foothills, in the Jhelum and Chenab valley outlets.

3. Glacially faceted boulders or boulders of foreign origin have so far been recorded only from the outlets of the largest rivers, the Indus, Poonch, and Chenab-Tawi. As pointed out below, their origin can be traced to catastrophic floods released under influence of a glacial climate.

4. In all gravels effects of certain diagenetic changes and of weathering are to be seen, such as brown patination of pebbles in boulder fans composed of rocks rich in ferromagnesian minerals, calcareous cementation in ridge and plains gravels, and oxidation of sands and gravels in distinct zones suggestive of fossil subsoils. On the other hand, there are no sure traces of wind corrosion nor signs suggestive of a dry climate. Red coloring of the sandy matrix appears to be restricted to areas of multicolored bedrock, especially Murree beds, which show dark red-purplish tints.

The faunistic record is very poor compared with the wealth of fossils found in the underlying Pinjor zone; in fact, the "Upper Siwalik fauna" is practically nonexistent in this zone. Pilgrim (1910, p. 192, and 1913, p. 325) mentioned *Equus namadicus* and *Bubalus palaeindicus* from the conglomerate at Bubhor and, according to him, Lydekker collected these same forms from the "topmost Upper Siwaliks." A third fossil, *Boselaphus* cf. *namadicus*, was found in the same beds. We have collected indistinct remains of mammals such as *Bos*, camel, proboscidean and hippopotamus limb bones, as also crocodilian and chelonian bones from the conglomerate near Rawalpindi and Bhaun. Pilgrim himself suggested that these scanty records indicate a Pleistocene age for the Boulder conglomerate zone. As in our opinion the Pinjor fauna is early Pleistocene, we cannot help but assign a somewhat later age to these beds. Especially the occurrence of analogous types of horse and *Bos* in the middle Pleistocene Narbada zone of central India is indicative of close faunistic relationships.

The Problem of Drifted Foreign Boulders in the Potwar

In a foregoing chapter it was mentioned how the boulder fans appear to merge into glaciofluvial gravels belonging to the second glaciation. This observation is significant, in view of the claims of other writers (Theobald and Cotter) concerning the glacial or pseudoglacial origin of foreign blocks found associated with ancient stream channels in the foothills. Indeed, the appearance of "erratics" in this Himalayan foreland has puzzled every observer and given rise to heated discussions on their origin and analytical value. Hence it appears appropriate to discuss briefly their meaning in relation to the climate of the last Upper Siwalik stage.

Recently Cotter (1929) has scrutinized and assembled the data concerning the origin of these foreign boulders. According to him they are restricted to the neighborhood of the Indus Valley outlet east and south of Attock, where they also came under observation in 1935 by members of our party (pl. XXVI, 3). They are distributed, as Theobald (1880*a*) has shown in greater detail, along an ancient river channel which corresponds roughly to the present course of the Haro River, down to its junction with the Indus (fig. 152). West of Campbellpore they lie 150 feet above the present stream bed on an undulating plain underlain by older Upper Siwalik rocks and covered by coarse gravel 20 feet or more thick. Cotter

measured their size and found them to range in girth from 15 to 50 feet and in height from 6 to 12½ feet. Theobald saw others, north of Haripur, measuring even 140 feet in girth. They are of Attock slate or granitoid rock not found in the immediate vicinity, the granitoid rock occurring in the mountains north of the Attock district, more than 30 miles from their present position. Their foreign origin therefore cannot be disputed. No signs of glacial action can be seen on them—a fact which argues strongly against their being true erratics derived from moraines, but as Theobald has pointed out, the hardness of these rocks does not provide a favorable medium for preservation of glacial striae or facets. Their shape is subangular or angular, and the faces are reduced by long exposure and weathering, which is made apparent by desert varnish, presumably acquired during the time since the blocks weathered out from the gravel. In our opinion there can be no doubt that these boulders are embedded in the plains gravel, because they are closely associated with the drift in which are found pebbles of similar slate and granite rock. Theobald's map (1880*a*) of the distribution also indicates clearly that they are restricted to a depression which, as he himself demonstrated, constitutes an abandoned Indus channel. In spite of this, Theobald denied their being part of the gravel; in fact, he considered them of later date and derived from "moraines," one of which he described from Barakot, north of Haripur. Yet, in his own words (1880*a*, p. 232), this "moraine" is a "coarse, stratified boulder gravel," a description not apt to strengthen his diagnosis. It so happens that a similar boulder deposit occurs at Jassian (Cotter, 1929), near Campbellpore, in a depression between two low ridges. This is composed of unassorted blocks of Cretaceous, Eocene, Attock slate, or gneissic formations. We saw another such boulder bed on the left, higher bank of the Haro River at Jassian, characterized by angular boulders in a matrix of silt and sand. In all these places the boulders keep to a higher level, which is the same elevated flood plain on which the gravel is encountered. This surface obviously is a dissected river plain of a large stream which, undoubtedly, issued from the mountains a few miles to the northwest, where a depression still indicates a branch of the Indus River. In view of the absence of any lake beds associated with the bouldery gravel, it is difficult to uphold Theobald's explanation, according to which the boulders were drifted by ice blocks off the snout of an Indus Glacier and floated across a glacial lake. As neither lake nor moraine deposits that could be definitely assigned to this stage are found in this area, it is evident that these boulders must have drifted with the plains gravel. Their large size requires a special kind of agency which was able to move these rocks over many miles of country. This agency, said Cotter, was provided by avalanchelike mud flows that were released by the bursting of a temporary dam in the Indus Valley above Attock. Previously Wynne (1879) had cited the historic Indus floods of the years 1811, 1831, 1841, 1856, and 1874, to prove that this valley has repeatedly experienced catastrophic inundations, most of which were caused by the bursting of glacial lakes in the upper Indus region. No other Himalayan river has a similar record of geologic cataclysms, as was once more shown in the flood of 1929, when a glacial lake in the upper

Shyok Valley burst, causing a devastating flood and sudden rise of the river at Attock. This unique phenomenon perhaps explains why the largest boulders in the Pleistocene plains gravel are restricted to the ancestral Indus Valley outlet east of Attock. Mud flows in the upper Indus region have also been described by many explorers, especially by Godwin-Austen and the Workmans, who observed them to reach a height of 45 feet, containing rolled boulders 6 feet in height and 10 feet in length. Just as these floods are the effects of present glacier movements, so was the boulder drift connected with a glacial climate of the past, as both Theobald and Cotter suspected. In view of the fact that the plains gravel is a facies of the Boulder conglomerate zone, which derived its components partly from glaciofluvial outwash of the second moraines in Kashmir, it is now possible to picture more clearly such catastrophic floods. The fact that the large blocks occur in the upper portion of the Boulder conglomerate zone makes us suspect a retreat stage of the second glaciation, during which glacial lakes were most likely to form in the upper reaches of the river. So much for the traveled blocks east of the Indus.

As stated by Wynne (1879, p. 133), the Soan and Jhelum tracts are free from large foreign boulders, and this is precisely what one would expect, in view of the absence of factors that would make for temporary ponding of water by tributary glaciers. For it must be remembered that the Jhelum Glacier moved through a deeply incised slope valley, in contrast to the upper Indus, which first followed a longitudinal valley before it reached the plains basin. There are, however, local occurrences of coarse angular débris southwest of Pindi Gheb and others along the flanks of the Salt Range. According to Theobald, the former are embedded in silt (loess), from which he concluded that they were derived from drift ice which floated across the "Potwar lake." It is, however, more likely that they slipped down from an adjoining limestone ridge during late Upper Siwalik time under the influence of periglacial frost weathering, which must repeatedly have supplied angular débris, transportation of which may have been facilitated by local floods. Both authors claimed that the blocks were often found on "terraces," implying a connection between boulder gravel and terrace formation. This can hardly be proved, as the upper terrace is cut into the boulder and plains gravel, which might well have caused the boulders to slip down, or simply weather out on the ancient flood plain.

As to the origin of boulder-bearing fans at the foot of the Potwar ridges, Cotter assumed that they also were caused by catastrophic river floods, which were released through the capture of longitudinal streams by transverse slope streams cutting backward as uplift proceeded. Evidence for this assumption is less readily available, as most of the longitudinal valleys in the Kala Chitta ridge are as yet undiverted. The Salt Range, on the other hand, provides a few examples which need no further emphasis, as this region lies outside of our territory. In the Kala Chitta and Khair-i-Murat ridges it is more plausible to connect the fans with a period of rejuvenation of the slope drainage.

Considering the coarseness and thickness of these beds it would appear that this stage was one of intense erosion in the highlands and of abundant water

supply. This is corroborated by the fauna and more so by the great ice advance in Kashmir. In the northwest Potwar region the drainage pattern undoubtedly was dominated by the Indus, while eastward the Jhelum drained the greater portion of the Salt Range, but not to the same extent as in previous times. In the Soan tract there is a marked predominance of limestone pebbles in the Boulder conglomerate, indicative of a strong supply from the ridges west and north of the valley and less so from the northeast, where the Jhelum deposited its load of igneous and metamorphic rocks. Perhaps this river had already shifted its braided channel southwestward in such a fashion that only a minor branch, the forerunner of the present Soan River, flowed northwest of the Salt Range. Such a pattern would readily explain why the Boulder conglomerate is so much thicker and coarser between Kahuta and Mirpur than in the Soan Valley.

Thus the landscape of this time must have presented a pleasing sight, with wide flood plains sufficiently covered by vegetation to allow abundant grazing for elephants, horses, and buffaloes. In their pursuit early man roamed over the country, leaving meager yet undeniable traces of his primitive skill in the form of flaked pebbles. Unquestionably, this crude cultural stage bore witness not only to his undeveloped intelligence but also to the geographic limitations of his habitat, as determined by river banks and the grazing grounds of the last survivors of the Siwalik fauna. Thus it is that the first appearance of man in this region coincides with the decline of that impressive mammalian empire which had left countless fossil records in the older Siwalik beds, in which is dimly documented an important stage of primate evolution.

POST-SIWALIK STAGES

Potwar Erosion

Except for local traces of high terrace gravels, the following stage was one of widespread erosion. Rivers trenched their flood plains, and tributaries cut an intricate pattern of gullies and canyons into the gravel-strewn Potwar plain. In short, the present drainage now developed, and the existing fold pattern in the Siwalik rocks guided its course wherever the streams lacked the power to cut through the resistant beds. This is exemplified by the trellis pattern developed on certain anticlines, as north of Dhok Pathan, where the rivulets faithfully follow the strike of least resistant clay beds in the Chinji and Dhok Pathan zones. The present Soan River presumably came into existence, and so did the recent Jhelum course. This can be deduced from the lack of any younger coarse river sediments in old channels such as the Soan, and also from the irregular land surface that underlies the Potwar loessic silt (fig. 172). It is this burial of the dissected Potwar under the loess which preserved its land forms. Ever since, except for the last Pleistocene stage, the geologic history has been one of re-excavation and deepening of this relief.

The drainage, which had so far been dominated by the ancestral Jhelum, now underwent profound changes. In the Soan Valley, where all stages have been so carefully recorded, there is only a thin high terrace gravel attributable to this

stage. It appears on both valley flanks near Rawalpindi, where it carries early paleolithic implements. This oldest terrace gravel of the Soan is composed mainly of limestone and Murree and Siwalik rocks; pebbles of Paleozoic formations are rare and seem to be derived from Dhok Pathan conglomerates. There is no trace of heavy river sedimentation, but rather the gravel depicts a medium-sized river, such as the Soan of our time. In other words, the Jhelum branch had been severed from the Soan depression, and we can reasonably assume that this was due to a rise of the anticline northwest of Panjar. The Jhelum now entrenched itself below Owen and cut through a boulder fan which had previously been deposited by one of its braided channels. For here, according to Wadia (1928, p. 361), the river passes through 7,000 feet of folded Upper Siwalik beds. Similarly, the Indus must have.shifted its course to the depression above Attock, thereby abandoning the ancestral Haro channel. Along this river there are no indications of heavy drift such as exist on the banks of the Indus, and the valley cut into the boulder-bearing plains gravel measures only a few hundred feet in width, indicating a much reduced erosion. The widespread dissection of the Potwar area was undoubtedly the result of diastrophic events, traces of which are found all over the area.

This diastrophism was a revival of those same uplifting and folding tendencies which are manifested in the fold-thrust pattern (fig. 6). While in the foothills anticlines rose and synclines experienced further compression, the Potwar ridges, such as Kala Chitta and Khair-i-Murat, gained in altitude probably owing to faulting, "posthumous" to earlier thrust faults. The tilting of ridge gravels in the central Salt Range and the faulting of fans on its southern slope signify similar events. Consequently, the Soan synclinorium suffered compression leading to a shallow folding and warping of Upper Siwalik beds. The Rakh Dungi ridge, on the right bank of the Soan near Chauntra, shows Pinjor and Boulder conglomerate beds with shallow anticlinal structure (fig. 170). Significant also is the fact that a northern border fault, northwest of Rawalpindi, became active, tilting boulder gravels to an angle of 85° (pl. XXVI, 4).

To judge from the position of the Potwar loess above the dissected Potwar surface, it would seem that the tributaries entrenched themselves more rapidly than the master streams. Their slopes, wherever they have been exhumed, are steeper than the flanks of the Soan Valley, owing, no doubt, to the more stable gradient and width of that valley. In fact, many of the smaller streams must have originated in this stage, especially those subsequent streams that drained newly uplifted tracts. This relationship explains why terrace formation was restricted to the major valleys, for here vertical erosion should have been displaced more quickly by lateral cutting. As in Kashmir and Poonch, a high terrace (T1) is encountered in the Soan, Haro, and Indus tracts. This terrace is in parts aggradational, as the gravel cover indicates, and this is not surprising, in view of the greater load of sediments which the main slope streams transported from the areas of main uplift. Actual reconnaissance of this terrace is often difficult, but in such places as are illustrated by figures 158 and 161, it is plain that the level

of the terrace is lower than that of the peneplain or of the depositional Boulder conglomerate surface and higher than the floor of the "Potwar gravel" below the loess.[1]

In this terrace gravel and also on its level surface were found the early paleolithic industries described in section E below. The rolled condition of these artifacts would suggest that they were manufactured on near-by land and subsequently redeposited in river alluvium; but in our opinion this does not warrant the conclusion that they were washed out from much older formations, for no hand axes or true Soan implements were found in Upper Siwalik beds. Also, the time interval between the deposition of the last Boulder conglomerate layers and the terrace formation was unquestionably very long, as we have records of both Chellean and Acheulian industries, the evolution of which presumably was a slow process. In Kashmir also the second interglacial stage was the longest, three major geologic events testifying to a prolonged interval between two glaciations.

This correlation between the Potwar stage of erosion and the second interglacial stage in Kashmir is based not only on terrace records but on geologic analogies as well, as both regions have in common dissection of fans. Although in Kashmir lacustrine beds and wind-borne drift were preserved, the Potwar bears only a meager sedimentary record in the form of terrace gravels. Considering that eolian sediments are present in the Pinjor and in the younger Potwar beds, it is likely that wind-blown dust also settled during this stage, especially in view of the intense glaciation which preceded it in the neighboring tract. If such an interglacial loess was ever present in the region it must have fallen prey to subsequent erosion.

Obviously, climatic conditions were drier than in the previous stage, and the archeologic sites suggest that people settled temporarily but repeatedly and over long time periods in this area. There are no fossils to indicate what their animal contemporaries were, but obviously the region must have offered a habitat sufficiently attractive to the Pleistocene hunters. The fauna may have been similar to that of the Narbada Valley, in central India, where the Chelleo-Acheulian implements were found associated with remains of horse, buffalo, straight-tusked elephant, and hippopotamus. Indeed, it is this association of the early paleolithic with a middle Pleistocene type of fauna which corroborates the stratigraphic position of these cultures in the middle Pleistocene of the Potwar.

Loess Stage

Physiographic aspect.—A mantle of yellow and pinkish silt covers the dissected relief of the Potwar and elevated ridges (pl. XXV, 3). This is the "loess" of earlier writers and our "Potwar loessic silt" (De Terra and Teilhard, 1936). Where it spreads across remnants of the peneplain it makes for an even surface, which stretches monotonously across the Soan depression. On higher ground, as on the Salt Range slopes and in its centrally situated valleys, brownish-yellow silt fills the valleys, and buries the older Pleistocene drift in the foothills. At many places

[1] The term "loess" is here often employed descriptively as a synonym of "loessic silt," which is perhaps more correct.

it makes for a typical loess landscape with vertical canyons, 300 feet deep, as north of Chakwal or in the vicinity of Rawalpindi; and again, south of Gujar Khan (pl. XXVII, 1). From its gray dust-ridden expanse, as if drowned under a thick veil, emerge the gravel and sandstone ridges of Siwalik and earlier rocks. This formation is so strikingly different from all other sediments which had formerly accumulated in the foothills that even the untrained observer is struck with this strange superposition. Where formerly change of facies and of color had dominated the foothill sedimentation, there occurred suddenly a uniform settling of wind-borne dust, shifted about by rain wash and rivers and accumulating a thick mantle of finest silt. This event clearly marks the end of the Siwalik series and the beginning of a new stage or at least one which was more perfectly preserved than the records of previous eolian intervals. To those who are acquainted with the loess on the corresponding flank of the Himalayan belt in Sinkiang or with the loess plateau of North China, this Indian loess landscape is at once arresting, both by its physiographic analogies and by its structural differences.

Structure.—The Potwar silt, although similar in texture to the loess of China, differs structurally from it in being stratified or coarsely laminated. There are places where it is structureless, but these seem to be exceptions rather than the rule.

Wherever a high vertical cliff is studied, horizontal layering may be seen, with the bedding planes from 5 to 20 or 30 feet apart (pl. XXVII, 1). In other places, such as the Soan and Sil valleys southwest of Rawalpindi, the silt is more finely laminated, like a lake bed. Along slope contacts or on mountain flanks the layers adjust themselves to the slope relief, as near Bhaun and on the southern flank of the Khair-i-Murat ridge. In addition, the silt is locally slightly tilted and warped, as exposed in the ravines 5 miles northwest of Rawalpindi, where it is banked against an anticline in Murree rocks. A closer view of such exposures reveals that the layers differ both in color and in composition. Light-yellow and brown or faintly pinkish strata interchange with each other, and many of the bedding planes show a thin film of clay matter. These bedding planes appear to be parallel and horizontal in regions where the silt is thickest, as in the Soan and Sil valleys and in the depression 20 miles northwest of Rawalpindi, east of the Haro River, but on mountain or valley slopes disconformities may be seen which indicate successive overlaps.

The texture of the silt is in general uniformly fine, but the mineral grains are so angular as to suggest violent wind transport. (See Krynine's report, p. 247.) Unlike the Siwalik rocks, the loessic silt does not seem to increase its grain size toward the mountains, but, on the other hand, slight regional differences of color exist in the northeastern and southwestern Potwar. In the former area faint pink or brownish tints predominate, owing, no doubt, to a local supply of silt from underlying purple and red Murree rocks. In other regions, as in Poonch and Jammu, no local supply of coloring matter could be detected in spite of the abundance of variegated Siwalik beds in this region. On the northern Salt Range slope, also at Chinji, yellow silt overlies red beds of the Lower and Middle Siwaliks, without showing the slightest discoloring. Locally thin layers of marl or small

concretions are found, yet the concretions never assume the size of the "loess-kindeln" characteristic of the loess of central Europe and China. It is doubtful whether the boulders mentioned by Theobald and Wynne actually occur in this zone, as no coarse débris was observed by us. More probably these authors referred to an older silt associated with the plains gravel of late Upper Siwalik time.

Fossil records.—Another important feature is the scarcity of vertebrate remains; it is even doubtful whether any have been collected from the yellow silt. Wynne (1877, p. 123) mentioned a find of camel (?) bones from the trans-Indus region near Ispinhak, but this was reported from gravels in a series of yellow, pink, and greenish silt and sand which presumably constitutes the "Potwar gravel" at the base of the silt. Wadia (1928, p. 290) indicated the presence of dog, horse, camel, and oxen without giving localities. An oral communication from Mr. Wadia revealed that tooth fragments of horse and dog were actually extracted from the loess on the south bank of the Soan River near Gorakpur. Considering the wealth of excellent exposures in the loess region it is indicative of the poverty of the fauna that so few vertebrate fossils have so far been found.

Fossil invertebrates, however, both mollusks and gastropods, are known from various places. North of Rawalpindi we collected a number of fresh-water mollusks belonging to *Limnea rufuscens h.* embedded in a laminated pink silt. Much more common are land forms such as *Planorbis exustus* and *P. convexiusculus*. Theobald (1877, p. 141) mentioned a lacustrine marl with beds of tufa southeast of Fatahjang, crowded with land and fresh-water shells. He listed the following forms:

Limnea rufuscens h.	Corbicula sp.
Planorbis exustus	Unio sp.
P. convexiusculus	Macrochlamys jacquemonti
Vivipara bengalensis	Cylendrus insularis
Bythinia pulchella	Napoens salsicola
Melania tuberculata	Opeas gracilis

This deposit evidently belongs to the tufa horizon which is generally developed on loess, or near hot- or ground-water springs. This tufa is presumably of somewhat later date than the loessic silt, and the fauna cited from it is not typical for this stage. In the course of 3 months of field work we found only one locality with fresh-water shells, while numerous others yielded land forms only.

Stratigraphic comments.—Although silt is the dominant sediment of this zone, it is for stratigraphic reasons important that at its base are found unconsolidated gravels and sands. In this respect the Potwar silt again resembles the loess of China, especially the "Malan loess," which begins with basal gravels and sand. In our region this layer is of especial significance, in view of the prehistoric industries ("early Soan") which it contains. (See Paterson's section on the prehistory of the Potwar and Indus regions.)

As can be seen from the sections, the basal or "Potwar gravel" varies greatly both in composition and in thickness. At some places it measures 2 to 3 feet or a few inches only, consisting of subangular detritus derived from local slope wash; at others, however, it forms a thicker series of gravel and gray-greenish or pink sand

of foreign derivation, measuring 40 to 60 feet. It everywhere lies unconformably over older folded or tilted beds and generally increases toward the valley center. This is strikingly revealed in the Soan tract between Adial and Chauntra, where the gravel makes a 10-inch layer on the peneplain surface southwest of Khair-i-Murat, whereas on the right Soan bank it is over 20 feet thick. Its greatest thickness was encountered about 10 miles west of Hasan Abdal on the Grand Trunk Road, where 35 feet of Potwar silt conformably overlies 60 feet of sand with gravel layers. On page 188 it is shown that in the foothills of Jammu it builds the second terrace (T2) of third glacial age, with over 100 feet of bouldery gravel. (See figs. 127, 135, 136.) On the banks of the Indus, near the confluence of the Soan River, Potwar silt is conformably underlain by 5 feet of gravel which caps the upturned edges of Upper Siwalik beds (fig. 181). Here, as well as in all the other valleys, the basal Potwar gravel represents a fluvial channel filling which gains in thickness upstream toward the mountain front. In other words, it signifies an aggradational stage following the prolonged period of erosion which dissected the Potwar plain. On the mountain border this gravel generally forms a terraced fan within the dissected Boulder conglomerate fans (fig. 109).

Taken together, both silt and basal gravel make a distinct stratigraphic zone of post-Upper Siwalik age which is connected with the formation of an aggradational river terrace (T2). Its geologic characters call for at least two subphases, fluvial and loessic, of which the latter demands special consideration.

Origin of Potwar loess.—From the foregoing description of the loess it would seem that the rivers at first graded their courses, filling the major channels with detritus until deposition of silt began. This deposit unquestionably required special agencies for its deposition, as it combines the characters usually ascribed to either wind-borne, fluvial, or lacustrine sediments. Petrologically and faunistically it is a loess, but its structure is more like that of a lake deposit, hence the difference of opinion as to its origin. For while Theobald and Wynne identify this formation with a lake which was to have covered the Potwar, Wadia and Cotter refer to it as loess. The lake, said Theobald (1877), was formed by the uplift of Potwar ridges, which dammed the slope streams. Indeed, the crustal mobility of these anticlines would suggest this uplift, but apart from the fact that the Potwar is open to the south, its loess cover spreads beyond the physiographic boundaries demanded by previous writers. It was found by us in the foothills of Poonch and Jammu, on the slope of the Pabbi Hills, and in the lake basins of the central Salt Range (fig. 153). In all these places it has the same characteristics as in the Potwar proper, and everywhere it is underlain by gravel and sand. Its position near Udhampur and in the Chenab outlet is sufficiently clear to identify the fluvial substage with the second terrace. (See p. 187.) This terrace is, in Kashmir, associated with the glaciofluvial action during the third glaciation, and loamy silt is known there as a terrace deposit. Simultaneously, in the upper Indus region, silt was stored up in vast quantities in lakes, even at places where local supply was poor (fig. 147). Probably the same formation builds a large part of the Ganges alluvium. This regional extension over plains and mountains alike indicates

an agency of sedimentation that was not primarily dependent on physiographic features or structural changes in the land surface.

There again it is more satisfactory to explain the past by the present. As mentioned previously, the Potwar, and for that matter the whole of northwestern India, is a region of great annual dust storms. Their greatest force is reached in the dry period before the monsoon rains break in April and May, when the air is often darkened for days by a dark-yellow haze of suspended dust, which rises in gigantic spirals and clouds from the Soan, Haro, Jhelum, and Indus valleys. The air is then usually heated to over 100° F., and its silt load is lifted up easily and drifted against the mountain rampart. Its outliers cross the high Pir Panjal and precipitate dust in the Vale of Kashmir, but the bulk of the matter settles in the foothills and near the valley outlets. Precipitation is effected both by air and by rain water, for the monsoon rains are instrumental in this process, falling over the southern mountain slope during June, July, and August. The first downpours are most effective; they deposit a film of silt one-eighth to one-tenth of an inch thick and frequently clear the air of all suspended dust. But intermittently storm winds whirl up silt from the valleys in the plains, causing a new addition to the seasonal precipitate. In this respect it is interesting to note that hardly any silt is lifted away from the Potwar loess sheet, but the main supply comes from the river alluvium in the places where it is as yet uncemented. This process must have been eminently more effective during a stage of mountain glaciation, because of the turbulent wind currents at the edge of the refrigerated highlands. Especially during a late glacial stage, when the Potwar rivers were well supplied with snow waters and when annual floods might temporarily have led locally to the formation of lakes in depressions, such a fluvial agency, combined with river and perhaps locally with lake sedimentation, probably stored up annually great quantities of silt. Periodical changes of rainfall or wind currents may have led to layering, which was accentuated by intermittent drying and chemical weathering. Such joint action alone can explain the presence of loess in such varying altitudes as 800 to 2,200 feet, and it may account for the disconformities and the horizontal banding along slopes and in larger depressions (pl. XXVII, 1).

Early man must have witnessed the beginning of this dust-storm period, for his tools and "workshops" were found in the lower 20 feet of the silt. The industry represented is a developed Levallois and certainly an improvement over the Soan tools found in the basal Potwar gravel. It is the fourth important industry in our Pleistocene sequence, in which the thin quartzite blades and scrapers already suggest a new skill in stone flaking such as characterized the Mousterian in Europe. The workshops found in the Soan area all lie on peneplain or terrace levels, where the "loess" is stratified. Now, it is obvious that the people did not live at the bottom of a swamp, but on dry land removed from the danger of floods and lurking beasts. Hence the layering found in the yellow silt is unquestionably not of fluvial origin.

The wind-borne nature of the silt and its high percentage of carbonate of lime may account for the absence of fossil vertebrate remains. True loess is rarely a favorable medium for the preservation of bones, and even the alluvial silt that

entombed the ancient cities of 5,000 years ago in the lower Indus Valley, in Iraq, and in Mesopotamia is peculiarly poor in skeletal remains. The bleaching effect of ground water charged with lime and percolating through porous silt is presumably responsible for this lack. At many places the Potwar loess exhibits residual soils made up of cemented breccia or concretions, which testify to weathering agencies. Such fossil soils are more frequently encountered in ill-drained areas, such as the high terrace and peneplain levels near the Soan, where they abound at fairly even horizons in the upper 30 feet.

Late Pleistocene

Third terrace.—In the Potwar region loess is by no means restricted to one stage. As I have previously pointed out, it is much more likely that throughout Pleistocene time eolian drift settled over the region, and only a portion of these records were preserved. Thus the Potwar loess formation was followed by another phase during which river and wind drift accumulated rapidly in the large depressions. On the Soan, southwest of Rawalpindi, and even more so between Gujar Khan and Sohawa, the loess is sharply dissected and the valleys are filled with a pink to brown silty loam. This deposit has been referred to as "redeposited Potwar" (De Terra and Teilhard, 1936), but it is more appropriately called loessic loam, as its formation is not entirely due to redeposition of the loess. Everywhere the loam occupies the lower river terraces, filling the gullies and canyons previously excavated. This dissection must represent a long period, occupying at best a full stage between the Potwar zone and the loessic loam, for it is recorded by the formation of a degradational terrace. North of Rawalpindi (fig. 158) a wide terrace is cut into the Potwar loess, leveling hard Murree sandstone. The intermediate position between a low aggradational terrace (T4) and an upper terrace (T2) or fan characterizes it as the same erosional stage which is regionally documented in Kashmir, Poonch, and Jammu as terrace 3. In the Soan Valley, upstream from Bandhar, this stream level is beautifully represented in an almost complete set of four terraces (pl. XXVIII, 2). As it usually developed on Potwar loess, its level varies greatly according to the erosive stream power and the original thickness of the loess. Often the stream, after denuding the loess, degraded on underlying harder Siwalik rocks. In the upper Soan Valley such a level was found 160 feet below the peneplain surface and about 55 feet above the stream, indicating a prolonged interval of graded stream action on bedrock.

In the upper Soan Valley and in the Indus Valley below Attock the third terrace is well developed, but in the Soan and Sil valleys below Rawalpindi it is usually missing. The right bank above Chauntra carries what looks like dissected remnants of a uniform terrace level, but there is no way of telling whether this is not merely a ledge of a resistant gravel above Pinjor clays.

The position of this terrace within the entire sequence is such as to make it almost certain that it originated during the third interglacial stage.

Fourth terrace.—A prominent slope 30 to 40 feet high separated the third terrace from a lower level which we identify with T4. This is because it is formed

as in Kashmir by aggradation of the valley floors, which here led to the deposition of loessic loam and sand instead of gravel, as in the mountainous tract. On the Soan it is well preserved at Sihala, where it builds a wide valley flat some 20 feet above the stream. This level is seen to extend into almost every tributary valley where its sand and silty loam rest against Potwar loess. It is present also along the Indus, Haro, Sil, and Bunha rivers, and it was previously described from the Jhelum, Poonch, and Chenab outlets. In all these occurrences T4 is composed of pinkish loam with interspersed sandy, gravelly layers, which increase in thickness toward the mountains, until, at the outlets, they are composed mainly of gravel topped by a thin veneer of silt—a composition which is typical of the same terrace in Kashmir.

Hence it would seem that, in contrast to the previous Potwar loess, this deposit is not so much a wind-borne as a river deposit. And yet, in deeper depressions, as between the limestone ridges east of Campbellpore, and more so in the upper reaches of the Kanshi River, 6 miles southeast of Gujar Khan, the terrace gravel is overlain by stratified loam of great thickness resembling the stratigraphic composition of the Potwar (fig. 176). In such places it is often difficult to differentiate between the two formations, especially if their disconformable contact is hidden from view, but even then closer inspection will show that the younger silt is less pure and more tinted than the loess. The fineness of grain in the younger terrace silt makes one suspect an eolian supply, and this view is strengthened by our observation that it carries thin layers with charcoal, broken bones, and pottery. These culture layers appear, locally, at depths exceeding 100 feet, and as they are repeated at various levels, we conclude that they could not well have accumulated as river drift, but that they were, time and again, built under eolian silt, which may have been intermittently redeposited under flood conditions.

Furthermore, the presence of pottery indicates a time range of deposition that embraces both late Pleistocene and Recent stages. This became especially apparent when human burials were uncovered from analogous deposits in the central Salt Range near Uchali and southeast of Rawalpindi, near Riwat. At these places skeletal remains of *Homo sapiens* of dolichocephalic type were found with funerary pottery in a yellow loess that overlies Potwar silt (pl. XXIX, 1). Although no archeologic data are yet available to prove equal age for the loessic soils found on higher levels and the loessic loam in the depressions, it appears nevertheless likely that such is actually the case. There are, in addition, indications of the formation of older wash deposits on the peneplain and associated terraces which contain a late paleolithic type of industry. The surface site above Adial, in the Soan Valley (pl. XXVI, 1), for instance, yielded what Paterson has called "late Soan," which is characterized by keeled scrapers and high-angle burins. Stray finds of microliths made of brown jasper or flint that may have been derived from a fossil soil of subrecent origin were collected from the Potwar loess surface. To such a later stage we may also assign the chipped pieces of limestone and flint found on ancient lake terraces and previously described by Hawkes (1934). Here, at Uchali, west of Naushahra, in 1935, we found associated with the implement-

bearing layers a burial which yielded hand-made pottery, presumably of neolithic type (fig. 152, loc. 20).

In short, it would seem that this last Pleistocene stage comprised both terrace formation and deposition of loessic soils, the latter being uniformly present in valleys and on higher ground, representing a time range from late Pleistocene to subrecent. The few archeologic records indicate that it is this stage to which prehistorians may look for the transition between paleolithic and neolithic cultures, and the geologist may turn with profit to a study of loessic soils and other deposits that are apt to shed light on the postglacial climate of this region.

Tufa.—In this respect it is noteworthy that tufa occurs at many places all over the Potwar region. We can distinguish at least three different types of occurrence—(1) in the vicinity of thermal springs such as 1½ miles north of Golra, where it is rich in leaf impressions (pl. XXVI, 4); (2) on the peneplain surface developed on Potwar loess or on gravels and usually not so very fossiliferous; (3) over limestone or impervious rocks on ledges that serve as outlets of the groundwater table. At the last-named places tufa is still being formed, and leaves and grasses are being incrusted with carbonate of lime. However, at Golra the plants belong to genera that are not now growing in the vicinity, such as *Tilia*, *Salix*, and *Quercus*. This assemblage indicates a wetter and somewhat colder climate than the Potwar has now, and it also suggests a considerable geologic age. From a block of tufa found near Sang Jani came the skull of *Bos* now on exhibit in the local museum at Campbellpore. The formation of tufa may correspond in age to the latest Pleistocene and subrecent stages, when the ground-water table was generally higher than at present and the subsurface water more heavily charged with lime. The lime undoubtedly is provided partly by the loess and partly by Eocene bedrock. In view of its young geologic age we doubt whether tufa, which usually forms resistant caps on loess or gravel ridges, will yield very ancient archeologic remains of man. (See Wadia, 1928.) Of greater promise are, in our opinion, the loessic soils, for they not only recorded a much longer time range but provided for a widespread and more favorable medium of preservation, at least so far as stone tools are concerned. In this connection it is of interest that the human bones found in loessic top soils are greatly bleached and very brittle—a condition which explains, perhaps, the dearth of skeletal remains in the Potwar loess.

B. GEOLOGIC SECTIONS THROUGH CULTURE-BEARING PLEISTOCENE DEPOSITS OF THE POTWAR

The accompanying cross sections may serve to illustrate the geologic history as outlined in the previous section. At the same time they provide the stratigraphic data necessary to a determination of the respective ages of the various human industries found between the Indus and Jhelum rivers. Most sections are indexed on figure 152, and on all are indicated in uniform letters various Pleistocene and earlier stages. In the text frequent reference is made to the 13 sections that De Terra and Teilhard published in a summary paper in 1936. Where necessary, these sections have been reused, but to avoid repetition we will refrain from de-

scribing them in any detail. In general, only those geologic profiles are presented which have a vital bearing on either geologic or archeologic problems. There are others in our possession which would perhaps throw additional light on stratigraphic details, yet it was felt that these data would not contribute essentially to the major task, which combines both the geologic and the archeologic history of man in India.

SOAN VALLEY

Nowhere else in the Potwar is the Pleistocene history so well recorded as along the Soan River and its tributaries. Beginning with the northern Potwar, the most important feature here is the geologic relation between boulder fans, the Potwar loess, and the terraces. In this respect the Kurang Valley furnishes good exposures, as its stream and tributaries descend from the Murree hills, joining the Soan near Rawalpindi (fig. 152, near Barakao).

Section 1 (fig. 158) gives the three major elements mentioned above, and among them the Boulder conglomerate fan commands our attention. The fan

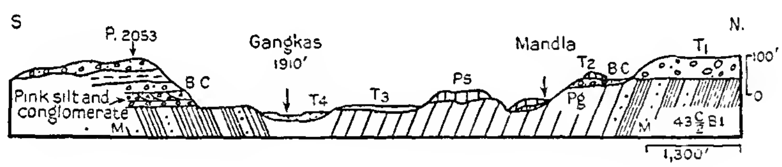


FIGURE 158.—Generalized section through Kurang Valley (section 1). M, Murree rocks; B.C., Boulder conglomerate; T1, T2, etc., terraces; Ps, Potwar silt; Pg, Potwar gravel.

issues from the foothills where Eocene limestone is thrust-faulted, making a fault-line escarpment of some prominence (fig. 6 and pl. XXVII, 2). At the outlet the fan is charged with angular boulders 2 to 5 feet long, in a sandy matrix which reveals heavy slope wash and river action of unusual power, such as was typical for the "fan stage" of the second glaciation. Moreover, 2 miles south of this locality the section exposes a facies typical for the Boulder conglomerate in the Soan Valley—namely, pink sandy grit overlain by boulder-bearing cemented limestone conglomerate. This formation extends, in the form of isolated low ridges and hillocks, all along the mountain front, and in all larger valleys it can be followed upstream into the mountains. Along the Kurang River Wadia (1928, map) has mapped several of these gravel patches, which rise 100 to 200 feet above stream level.[1] Many of these conglomerates simply cap residual ridges of Murree sandstone, but taken together they form a coherent, broad fan 3 to 4 miles wide and dissected by slope streams. The correlation with the Boulder conglomerate of Upper Siwalik age is further emphasized by the terraces cut into the fan. The section shows four levels, of which the upper two are seen only at the outlet where the fan surface is terraced. Fifty feet below T1 a second terrace is found, and its

[1] Hand-colored Geological Survey sheets on a scale of 1 inch to 1 mile were made available through the kindness of the Director of the Geological Survey of India and were of great help in our studies.

boulder gravel rests against the slope below the upper level. This gravel belongs to a fan which thins out rapidly to the south, making a basal gravelly sand below the Potwar loess. It signifies aggradation, which followed trenching of the stream, and therefore suggests the younger fan stage previously ascribed to the third ice advance. The Potwar loess buries this terrace, but it obviously belongs to the same stage. The third terrace is most conspicuous as a wide flat, covered with brown silty loam (pl. XXVII, 2). As it bevels bedrock, it must belong to that degradational stage in which the wide third terrace of Poonch and Jammu originated and which we correlated with the third interglacial stage of Kashmir. Below it, underlain by gravelly silt and loam, lies T4. It marks the last filling of the youngest valley during a period of much weakened transporting power. The analogy of this terrace system with that found in Kashmir is such as to make it fairly certain that the boulder fan represents late Upper Siwalik time and that the northern Potwar underwent the same changes of stream level as the foothills in Poonch and Jammu.

The general section 2 (fig. 159) leads us farther south across 8 miles of Potwar loess. In it we have indicated the youngest "boundary fault" (F) of the Himalayan foothills as exposed north of Golra, about 10 miles west of our section. Here also the fan is composed of limestone detritus, which reappears on the southern slope of a ridge a few miles west of the profile. The Potwar surface slopes gently 100 feet toward the Lei River, a Soan tributary, which has cut the northern outlier of the Soan syncline. Here the Boulder conglomerate is over 200 feet thick and is well exposed about 2 miles southeast of Rawalpindi. This thickening of the Upper Siwalik fan is due to the synclinal subsidence that preserved a larger portion of the Boulder conglomerate.

Similar relations prevail near Kahūṭa, about 16 miles southeast of section 1. Figure 160 illustrates how the older Upper Siwalik beds (Tatrot-Pinjor) occupy a faulted syncline in Dhok Pathan rocks, which are unconformably overlain by Boulder conglomerate. Paleozoic and metamorphic rocks of Pir Panjal derivation make the bulk of this fan, reflecting the ancestral channel of the Jhelum. The pebbles range from 4 to 8 inches in diameter, and their matrix is brown and reddish. Here also gravel ridges rise a few hundred feet above the plain, and on them were collected stray artifacts belonging to the pre-Soan flake industry. Terraces 1 and 4 are represented in the form of isolated remnants, and the Potwar loess is seen to rest against the slope cut into the fan deposits.

In this neighborhood the late Pliocene peneplain surface is stripped from its Pleistocene cover, except for loess remnants, and cuts clear across Lower Siwalik beds (pl. XXVII, 3). As soon as the Soan is reached the terraces reappear, and east of Bandhar they are once more associated with Pleistocene beds. Here the conglomerates appear both in the form of a ridge and as a basin filling. The ridge carries a narrow ledge that might represent T1. The third terrace is cut into Potwar loess, which is always absent from the fourth terrace wherever that is preserved (pl. XXVIII, 2). Section 3 (fig. 161) may serve to illustrate the amount of denudation prior to the loess formation.

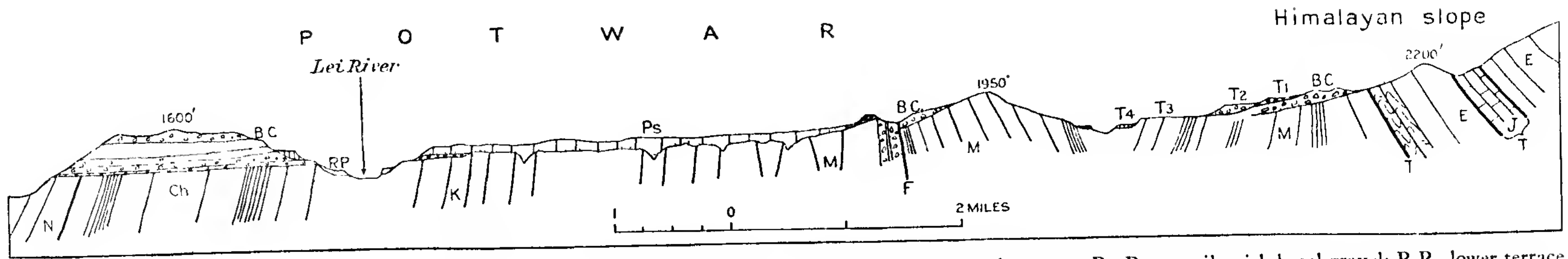


FIGURE 159.—Section through Potwar and foothills north of Rawalpindi (section 2). B.C., Boulder conglomerate; Ps, Potwar silt with basal gravel; R.P., lower terrace loam; J, Jurassic; other symbols as in figure 154.

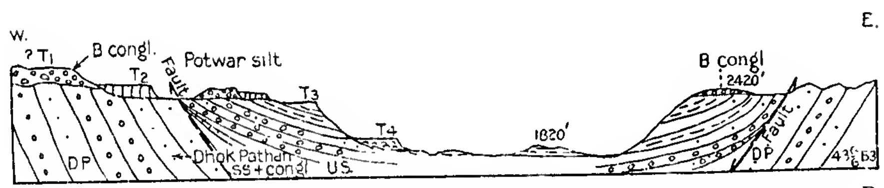


FIGURE 160.—Transverse section through Kahuta syncline. T1, T2, etc., terraces; B. congl., Boulder conglomerate; U.S., Upper Siwalik; D.P., Dhok Pathan.

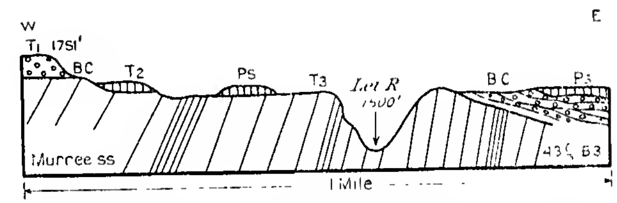


FIGURE 161.—Terraces (T1, T2, etc.) on left bank of Lei River east of Rawalpindi (section 3). B.C., Boulder conglomerate; Ps, Potwar silt.

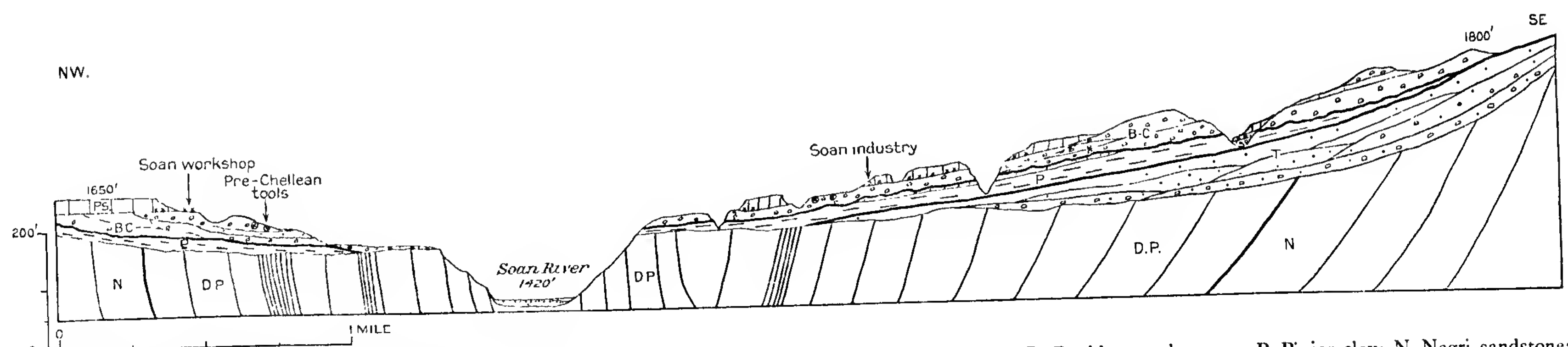


FIGURE 162.—Cross section through Soan syncline southeast of Rawalpindi (section 4). Ps, Potwar silt; B.C., Boulder conglomerate; P, Pinjor clay; N, Nagri sandstone; D.P., Dhok Pathan beds; T, Tatrot sandstone.

A general geologic profile through the Soan syncline has been described by De Terra and Teilhard (1936) and needs no further explanation. Section 4 (fig. 162) gives a generalized version of our interpretation. Noteworthy is the thick Upper Siwalik filling of the trough with the great unconformity at the base, which in nature is more irregular and better adjusted, on its southeast end, to the dip of early Pleistocene beds. The Soan, as will shortly be described, has here denuded the terraces, some of which reappear a few miles downstream. Of special interest in this section are the exposures on which implements were found. These are distributed on the left bank between the Grand Trunk Road at milestone 163 and the gravel-strewn ridge to the south and north of the road.

At 400 yards west and about 200 yards north from milestone 163, another section (fig. 163) was taken. The top layer is loess of yellow color with a slight pinkish tint at the base. This is underlain by a thin gravel made up mainly of limestone pebbles, which are not as well rolled as in the underlying conglomerate. This is 90 feet thick in places and alternates with pink silt and sand. Its components

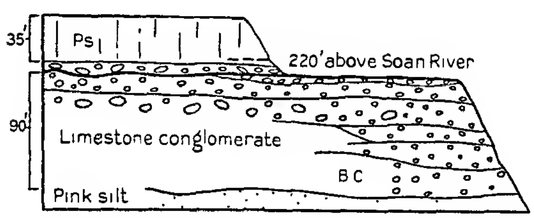


FIGURE 163.—Cross section through deposits of second to third glacial age on Grand Trunk Road southeast of Rawalpindi (section 5, not marked on fig. 152). Ps, Potwar silt; B.C., Boulder conglomerate.

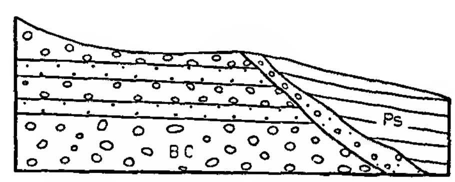


FIGURE 164.—Section showing Potwar beds as ancient valley fill on Boulder conglomerate south of Grand Trunk Road near Rawalpindi (section 7). Ps, Potwar silt; B.C., Boulder conglomerate.

are well rolled and exhibit a variety of rocks, with limestone and quartzite most abundant. The pebble size ranges from 2 to 4 inches, and brown patination prevails on metamorphic fragments. In view of the fact that the conglomerate grades into the pink sand and silt layers of Upper Siwalik age three-quarters of a mile southeast of the section we cannot doubt that this zone represents the Boulder conglomerate. Hence, between it and the basal Potwar gravel lies a disconformity, or hiatus, which doubtless represents the second interglacial stage. The few topmost inches of this gravel are firmly cemented by carbonate of lime, which suggests long exposure to weathering agencies. It is this layer that contains the oldest industry, represented by rolled crude hand axes of early Acheulian type (see pl. XXXI, C; and pre-Soan flakes, pl. XXXI, A). Very probably the conglomerate at this horizon is an old surface, or terrace remnant of T1, as it can be projected across the Soan to the ledge on the Boulder conglomerate ridge southeast of Rawalpindi (pl. XXVIII, 2).

A second culture stratum is found in the basal gravel of the loess, where early Soan tools occur in both rolled and unworn condition. This gravel is richer in implements, which display a great variety of tools, scalloped pebble choppers, scrapers, large Levallois cores, and flakes. Where loess and gravel have been

denuded such artifacts may be collected from the conglomerate surface, but these are heavily patinated and never incrusted with lime, as the gravel artifacts generally are. On the surface this culture is mixed with cores and flakes of early and later Levallois tradition.

A third implement-bearing zone appears in the lower few feet of the loess, which is here somewhat sandy. Here, from the vertical edge of the silt, we collected thin blades of greenish-gray quartzite, which represent a later stage of the Soan culture complex called late Soan B by Paterson. (See section E below, also pl. XLII). That these implements are in place is proved by the clear break of the loess slope and the freshness of the flake edges, which are as sharp as if they had just been manufactured.

Section 7 (fig. 164) gives a clearer view of the disconformable contact between Boulder conglomerate and the Potwar zone. It was taken half a mile southwest of section 5, in a ravine descending from the gravel ridge to the east. The Potwar gravel makes an old valley fill and is firmly cemented in places. Here

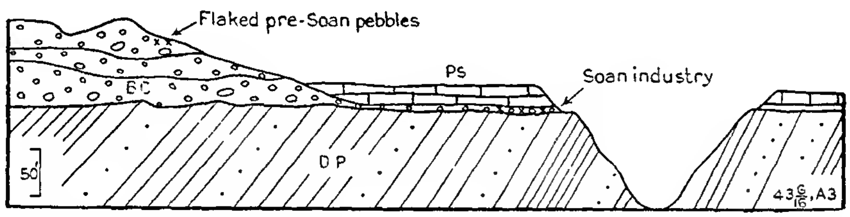


FIGURE 165—Generalized section 8, near Malakpur. Ps, Potwar silt; B.C., Boulder conglomerate.

was collected a fine, absolutely unworn specimen of the chopper type of late Soan A (pl. XL, 3,) and in addition cores and flakes of the same industry. It took 10 minutes' work with the chisel to extricate some of the artifacts from their lime matrix. The conglomerate shows alternating layers of brown sandy silt, which is characteristic for the lower portion of the Boulder conglomerate.

About 8 miles southeast of section 6 Teilhard and De Terra found, on the ledge of the Potwar loess plateau toward the Soan Valley, another site which is interesting on account of the exclusive occurrence there of Soan artifacts in the basal loess gravel. The locality lies south of Malakpur, on the left bank of the Kastril River, a Soan tributary, and 600 yards west of the hamlet of Mohra Bakhtan (topographic sheet 43 G/16, A3), on the path that leads from Malakpur south to Gakkar Sunal. Section 8 (fig. 165) shows fossiliferous Dhok Pathan beds (with *Hipparion*) in the southern limb of the Soan syncline, planed and covered by Boulder conglomerate and loess. The peneplain level is here exceedingly well preserved (pl. XXVII, 3). The conglomerate is some 120 feet thick and is composed mainly of Pir Panjal rocks, its pebbles bearing the brown patina so typical of the boulder fan facies (second glacial). The absence of limestone débris again suggests an ancestral Jhelum course, which flowed 210 feet above the present stream beds. From the surface of these ridges atop the peneplain were collected a few

flaked pebbles of the pre-Soan industry (pl. XXXI, A). These artifacts had weathered out from the top gravel layers, and, as there was no indication of a terrace or redeposition, we take it that they occur in place in the second glacial deposit.

Potwar beds are seen to rest against these ridges, veiling the peneplain level with basal gravel and pink sand (3 to 12 feet) and overlying loess (20 to 30 feet). The loess lies about 130 feet above the valley floor, breaking off with vertical walls (pl. XXVII, 3). At their base and from the loess gravel we collected, some 30 feet from the surface, many specimens of the late Soan type. Undoubtedly, these were manufactured on a terrace (? T3), which at that time was less dissected than now.

Southwest of Rawalpindi the Soan River has cut deeply into early Pleistocene beds and on its banks rise steep walls made of pink stratified silt and clay which we may in part identify with the Pinjor zone. The structural relation of these

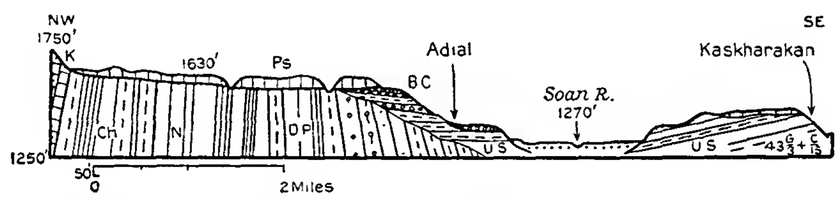


FIGURE 166.—Section 9, through Soan syncline at Adial. Ps, Potwar silt; B.C., Boulder conglomerate; Ch, rocks of Chinji stage; N, Nagri stage; K, Kamlial stage; D.P., Dhok Pathan beds; U.S., Upper Siwalik.

beds to later Pleistocene sediments is well exposed at Adial, where sections 9 and 10 (figs. 166, 167) were taken.

From the residual strike ridges of Kamlial sandstone (Miocene) across the Potwar peneplain to the Soan one encounters an almost complete stratigraphic sequence of Siwalik beds, from which only the Tatrot zone appears to be missing (fig. 166). The Dhok Pathan, as Cotter (1933) has already pointed out, is represented by hard conglomeratic sandstone and variegated clays, which Wadia (1928) has mapped as Upper Siwalik. The facies and structure of these beds, however, is so typical of the Dhok Pathan stage that we cannot doubt their Middle Siwalik age.[1] True enough, if they are Middle Siwalik the Upper Siwalik beds appear much reduced on this flank of the Soan Valley, where only Pinjor clays and thin conglomerate layers are exposed, but on the opposite bank Tatrot sandstones appear, as shown in section 5. Yet it is possible that Tatrot beds occur also on the right bank, where they may be simply hidden from view by later Upper Siwalik deposits. These beds represent a somewhat puzzling sequence, which seems to defy all efforts at stratigraphic classification. The difficulty is that the Boulder conglomerate facies appears to grade into the Pinjor clays, or at least there does not seem to be a clear break between the two. However, in all sections there is a distinct general division between an upper conglomerate, bearing pink grit and

[1] This view is also adopted by the geologists of the Attock Oil Co.

silt (200 to 500 feet thick), and a lower sandy-layered pink silt. The latter crops out in the lower slope regions, making, locally, straight bluffs 120 feet high, in which the warm red tints contrast with the gray-yellow colors of the Potwar loess (pl. XXVIII, 3). The upper zone is a facies of the Boulder conglomerate consisting of at least three major gravel beds, each 20 to 30 feet thick, alternating with pink sandy grit and silt. This river gravel is composed of both Eocene limestone and metamorphic pebbles, suggesting the ancestral Soan drainage of late Upper Siwalik time. Also, the artifacts, crude flakes of Cromerian type, found in one of the gravel layers, belong to the type of pre-Soan industry that characterizes the Boulder conglomerate fans near Kallar and Malakpur. Taking into account the facts that the Pinjor zone is devoid of human implements and that the loess bears specimens of a culture distinctly more developed than the pre-Soan industry, we have no other choice but to assign this group of alternating gravel and sandy grit to an intermediate stage—for example, to the Boulder conglomerate. As we are here dealing with the center of the Soan syncline, it is natural that these two zones,

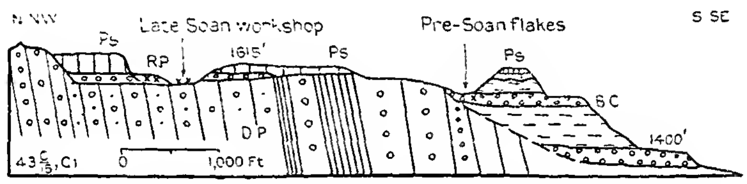


FIGURE 167.—Cross section 10, at locality 1, above Adial. Ps, Potwar silt; R.P., alluvial soil; B.C., Boulder conglomerate; D.P., Dhok Pathan beds.

which are elsewhere unconformable or disconformable on each other, are conformable at this locality.

With this in mind we must interpret section 10 (fig. 167), which was taken where the camel path from Adial ascends the right Soan slope toward Dhok Gangal. After ascending a low terrace (? T4) the path leads uphill across coarse limestone gravel, which crops out in resistant ledges. The adjoining glen exposes a high bluff of pink silt, overlain by a bank of conglomerate some 12 feet thick. This stratum is crossed by the path, which exposes the vertical dip of Dhok Pathan beds horizontally overlain by the conglomerate. This conglomerate is cut out at the edge of the peneplain, on which no Upper Siwalik sediments are encountered. A mile northward and about 300 yards south of an open tank lies the richest workshop site which our party located in the Potwar region. It was discovered by me in April 1935 and named "locality 1." It is an open gravel patch on Dhok Pathan conglomerate, measuring some 3,000 square feet, from which we collected 600 artifacts. The industries represented have been described by Paterson as "late Soan" (pls. XXXIX–XLII). Mixed with this industry are rolled early Soan tools and an Abbevillian-like hand ax.[1] This makes us suspect that there occurred repeated rewashing of certain implements from older (perhaps Potwar) gravels. At a

[1] According to Abbé H. Breuil, the term "Chellean" is to be replaced by "Abbevillian," because at Chelles no pre-Acheulian tools occur, whereas at Abbeville, on the lower Somme, they were found in a fresh state of preservation in association with fossils.

later time such redeposition did actually take place, as late Soan tools were also found near-by in an alluvial soil (R.P., fig. 167) presumably of late Pleistocene age. This soil apparently represents the latest wash deposit on the peneplain and is to be correlated with the "redeposited Potwar" or the latest river drift of terrace 4. The site lies some 200 feet above the Soan and holds a favorable position commanding a view across the plateau and into the Soan valley.

Another workshop was found at a similar level 300 yards to the west, and a third one lies about 500 yards due northeast from a tank south of Hassan Khan Dhok (topographic sheet 43 C/15, C1). The latter is apparently a residual deposit of the Potwar gravel, as the Potwar loess covers the peneplain uniformly. Accordingly the implements are somewhat rolled, but not so much so that we must necessarily assume river transport. The thinness of the basal gravel (1 to 3 feet) and the local deviation of the detritus indicate a slope-wash deposit on the old land surface, which at that time presented a real plateau on which the loess settled. It is also noteworthy that this basal gravel is composed mainly of pebbles washed out from the Dhok Pathan conglomerate. This deposit provided the Soan people

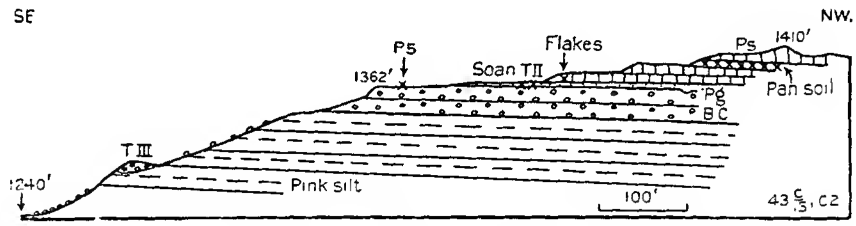


FIGURE 168.—Section of western slope of Soan Valley above Chauntra (section 11). TIII, TII, terraces; Ps, Potwar silt; Pg, Potwar gravel; B.C., Boulder conglomerate.

with ideal raw material for the manufacture of tools; in fact, all these sites are so closely associated with outcrops of the middle Pliocene conglomerates that one can almost predict sites wherever this formation underlies the peneplain.

To this cluster of sites belongs another workshop called "P.6" in our diary. It lies on the road that leads from Khasala Kalan, in the Soan Valley, up to the plateau to Hassan Khan Dhok, about 1½ miles due north of Khasala Kalan. The altitude of this place is about 100 feet below that of the former sites, and the workshop is found on limestone gravel belonging to the Boulder conglomerate zone. Large unutilized cores and waste flakes of early Soan type appear here in association with scrapers, choppers, and blades, all scattered over the ledge which the resistant gravel forms on the valley slope (pl. XXVIII, 1). This place can be reached by motor car from Rawalpindi on the road to Chauntra, and from it the other sites can be approached on foot within half an hour.

This site is transitional to another and most important group found associated with high terrace remnants. Sections 11 and 12 (figs. 168, 169) may illustrate their geologic position. Before we give a detailed description it is necessary to point out that the Boulder conglomerate east of Dhala village gains in thickness and width of outcrop to such extent that it forms a 600-foot ridge, known as

"Rakh Dungi." Its lower slopes expose pink silt and sand, presumably of Pinjor age, which are overlain by at least 500 feet of conglomerate and pink sand. One of the lower conglomerate layers makes a conspicuous terrace, which can be followed for several miles downstream. Two features indicate its origin from an old valley floor—first, its altitude diminishes downstream by 20 feet over 1½ miles; second, there are corresponding terrace remnants in the valley which are covered by ancient river deposits. (See fig. 169.) Loess is absent at the locality of section 12, but on the right slope loess buries the terrace, from which it was somewhat denuded, thereby leading to exhumation of part of the 100-foot terrace. At the edge of the loess occur two if not three different culture layers.

On the conglomerate was found a workshop composed of early Soan industries in which the artifacts had been obviously selected from the hardest quartzite, felsite, and trap pebbles. The specimens are patinated but not rolled (early Soan B–C), a condition which may at first seem to indicate that they were manufactured after the loess had been eroded from the slope. However, a real basal gravel of the loess is missing here; instead we find pinkish sand overlain by yellow loessic

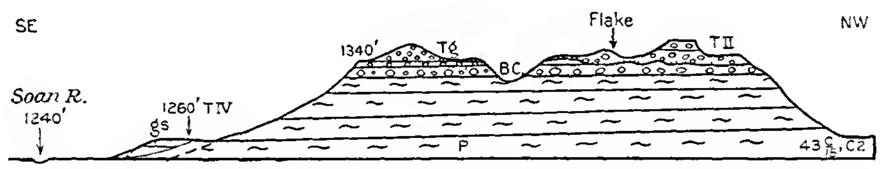


FIGURE 169.—Section 12, across gravel ridge at Hun, above Chauntra. gs, gravelly sand; TIV, TII, terraces; Tg, terrace gravel; B.C., Boulder conglomerate; P, Pinjor clay.

silt with a 3-foot layer of lime concretions (fig. 168, "pan soil"). The sand yielded a few thin blades of greenish quartzite of the developed Levallois type representing the "loess industry" of section 6 (pl. XLI). In view of the absence of the Potwar gravel it seems possible that the workshop originated on the terrace prior to loess deposition; that it was subsequently buried under wind drift and later reexcavated by slope wash. Such a process alone can account for local admixture of artifacts belonging to both early and late Soan types. The high altitude of this terrace ledge suggests that this is T2, of third glacial age.

In section 12 (fig. 169), which is 1½ miles southwest of section 11, Soan artifacts are missing. The 20 feet of loose terrace gravel and sand which overlie the hard Upper Siwalik conglomerate are of gray color, contrasting with the pink silt beneath. One large Clacton flake of quartzite was found in the terrace gravel.

To judge from the position of this terrace between loess and Upper Siwalik beds and from the presence of early paleolithic tools, there can be little doubt as to its representing the Soan level of the third glacial period or T2. The possibility of its being T3 is ruled out by differences in composition and altitude (see fig. 168) and T1 cannot well be expected in this region, considering that in the Soan Valley this level is always associated with Boulder conglomerate ridges, as seen in the exposures near Chauntra (section 13). In addition to this 100-foot level, there are indications of at least two younger terraces being present in this part of the Soan

Valley. The lowest (T4 ?) lies some 20 feet above the stream (fig. 169) and is built of pink sandy silt. The other is 50 feet above the Soan and underlain by 5 to 10 feet of loose limestone gravel, but its preservation is so fragmentary as to render its reconnaissance difficult. If these two lower terraces are compared with those found east of Rawalpindi, it is seen that the 50-foot terrace above Chauntra is at a level similar to that of T3. Its gravel could thus either be an ancient Soan drift of the Potwar gravel stage, in which the river lowered its course until it almost reached

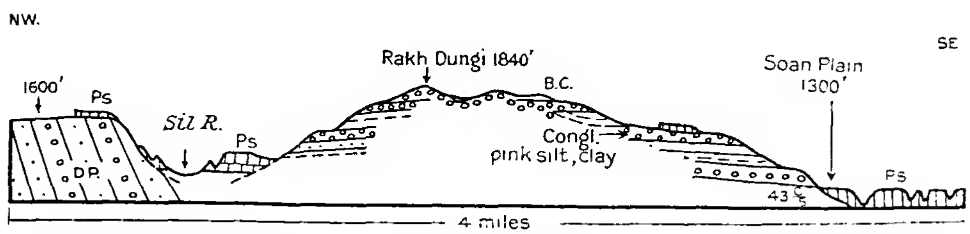


FIGURE 170.—Cross section through Rakh Dungi Ridge, opposite Chauntra (section 13). Ps, Potwar silt; B.C., Boulder conglomerate; D.P. Dhok Pathan beds.

the bed that it had occupied during the pre-Potwar interval (second interglacial stage), or it could be a new drift contemporary with the third terrace. In view of the degradational nature of T3 it is more likely that the lower terrace gravel preceded the third Soan level, and in that event the underlying river drift would represent a special Soan facies of the Potwar gravel.

The great Boulder conglomerate ridge of Rakh Dungi continues southwestward to Sihala, where the hills lose in height, merging, as it were, into some of the lower Soan terraces. A section (fig. 170) through the southeastern slope, taken 2 miles northeast of Sihala (section 13), confirms the complex composition of this

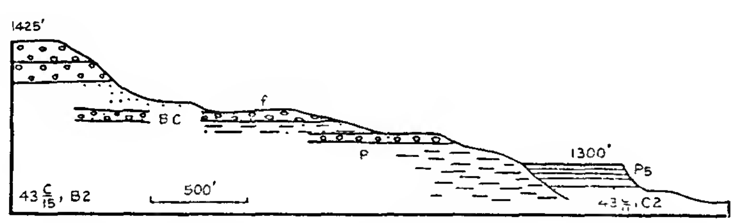


FIGURE 171.—Cross section 14, through eastern slope of Rakh Dungi Ridge. B.C., Boulder conglomerate; f, pre-Soan flakes on surface; P, paleolithic workshop; Ps, Potwar silt.

zone as previously deduced from upstream sections. Here also three major conglomerate layers appear above pink and red clays and silts, against which rests a 90-foot series of yellow loessic silt with pink sand at the base. Noteworthy is the low position of the base of the loess, indicating deep dissection of the Boulder conglomerate during the second interglacial stage. Section 14 (fig. 171) gives a clearer view of these relationships between loess and relief.

This difference in altitude between the Rakh Dungi (highest point 1,998 feet, not marked on map) and the peneplain level (about 1,600 feet) constitutes a

special problem, for if the former is middle Pleistocene and the latter late Pliocene, it must follow either that the conglomerate covered the planed Potwar surface more extensively in former times or that the peneplain has been recently uplifted. The lack of any thick Boulder conglomerate deposits on the adjoining land surface argues against the assumption that this gravel ridge is merely an erosional remnant of an ancient extensive peneplain deposit. On the other hand, its structure and position on the synclinal axis of the Soan depression not only explain the great thickness in a Pleistocene depression of the peneplain but indicate that the sinking tendency was followed by uplift, which caused the conglomerate to rise several hundred feet above the planed land. Both the Soan and the Sil rivers entrenched themselves on each flank of the ridge, creating a deep relief before the loess was

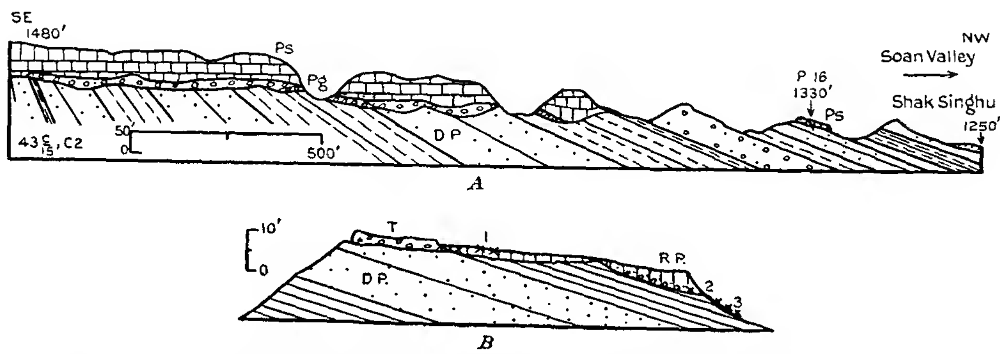


FIGURE 172.—*A*, Potwar loess (Ps) over synclinal structure of Siwalik beds southeast of Chauntra. Pg, Potwar gravel; P.16, hand-ax locality (see *B*); D.P., Dhok Pathan beds. *B*, Section 15, at Chauntra site, with ancient terrace gravel (T) overlain by redeposited Potwar silt (R.P.). 1, 2, 3, fossil localities; D.P., Dhok Pathan beds.

laid down. Presumably this relief resulted from erosion promoted by further compression of the Soan syncline, for the ridge has anticlinal structure, just like many of the boulder fans in the foothills of Jammu and Poonch. Hence the Soan tract recorded the same diastrophism which caused its flanking ridges, the Salt Range and Khair-i-Murat, to rise and become dissected. In other words, the Potwar shared, during the middle Pleistocene time, in the tectonic fate of the Himalayan hills, as it had done on previous occasions.

On the left bank of the Soan 2¼ miles southeast of Chauntra as the crow flies low gravel and sandstone ridges rise from the flood plain. These constitute resistant beds in the Dhok Pathan and Tatrot zones and are part of a dissected land surface, largely buried under loess and Potwar gravel (fig. 172, *A*). On the slope of the second row of hills and 500 yards southeast of Chakh (or Shak) Singhu village, Teilhard and De Terra discovered in November, 1935, a site with Abbevillian and Acheulian hand axes. As this is, so far, the first and only find of this type of paleolithic culture in our area, it is worth while to describe it in greater detail.

The locality (fig. 172, *B*) is 2 miles from the Soan River and only half that far from the dry flood plain. Its altitude is 80 feet above the Soan level, almost

on the slope crest of the second ridge, which is capped by a coarse gravel (pl. XXIX, 3). The gravel is composed of water-worn boulders and pebbles derived from Siwalik sandstones mainly, but there are also quartzite constituents such as occur in many of the ancient Soan terrace deposits. Its lower position in relation to the Potwar gravel is evident from figure 172, *A*, and as this basal loess gravel is of different color and composition, we conclude that the lower gravel represents a different terrace deposit. However, no true terrace flats are preserved in the neighborhood, but this is easily understood if one takes account of the friable nature of the underlying rock and the intense dissection which it has undergone on the slope of the syncline. Adjacent to this ridge gravel and banked up against the crest of the ridge lies a pinkish sandy silt in which were found some 100 artifacts of Abbevillian and Acheulian type (pl. XXXI, B). The hand axes are water-worn, the Abbevillian tools more so than the Lower and Middle Acheulian tools, and they occur in greater numbers near the high terrace ledge. This may indicate that they were washed out from the ridge gravel and redeposited at a later time when the pink sandy silt was formed. The pink silt makes a slope veneer and is charged with detritus of apparently eluvial type, from which we collected a number of late Acheulian hand axes, as well as cores and flakes of the late Soan industry (pl. XLIII, nos. 1, 2, 3, 6).

From these facts it would seem that there are two different deposits and at least two distinct types of industries. The ridge gravel can belong only to a fill stage during which the then less dissected slope was buried by ancient Soan drift. Although different in composition from the Potwar gravel, it might well represent a facies of the Potwar, for it lies nearer to the Soan tract than the higher Potwar gravels (fig. 172, *A*). In that event it would represent a terrace gravel of third glacial age on which the river subsequently degraded, thereby reducing its thickness greatly. This interpretation is supported by the altitude of the ridge gravel, which is intermediate between the 120-foot (third) and 20-foot (fourth) terraces of section 11 (fig. 168), which is only a few miles upstream from this locality. Hence, the gravel might be considered as of third glacial age while the adjoining sandy silt must be third interglacial, representing a thin deposit on T3. Accordingly, the early paleolithic hand axes were embedded in a third glacial deposit and redeposited in the following interglacial stage, together with late Soan tools. Now, in view of the occurrence in place of similar early Acheulian hand axes on level 220 feet of section 5 (fig. 163) it is probable that at Chauntra the same industry (with Abbevillian tools) originally was manufactured on a high terrace, which was subsequently denuded, and its artifacts incorporated in T2.

On higher ground the Potwar gravel (fig. 172, *A*) yielded Levallois flakes and cores, which are somewhat water-worn but always in place at the base of the loess. The ravines and gullies south from locality P.16 expose pink gravelly silt and sand overlain by stratified shell-bearing pinkish to yellow silt. The loess here reaches in single bluffs a thickness of 150 feet and must originally have been at least 250 to 300 feet thick. It is more sandy here than on the adjoining peneplain, where its thickness hardly exceeds 40 feet. This dependence of facies on the relief clearly

justifies our contention of the drift origin of the Potwar silt as described above. It would seem that the silt was blown away from the valley flats while the sand settled in the Soan depression, undergoing repeated redeposition by the stream. This is precisely what we observed during our stay in April, 1935, when a violent storm whirled up black clouds of silt that drifted from the Soan flats northeastward with gale force. During this storm the heaviest dust fall occurred in the depression. Such a process would account for the relative thinness of the loess on the plateau or on interstream divides.

An Acheulian hand ax was found farther downstream on the right bank 1 mile north of Balawal. Section 16 (fig. 173, *A*) shows the northwestern limb of the Soan syncline, composed of Dhok Pathan beds which Wadia (1928) had mapped as Upper Siwalik. However, from these beds we collected, at locality 99 of figure 173, *A*, *Mastodon*, *Merycopotamus*, and *Hipparion*, clearly indicating their Pliocene age. The peneplain is well developed in this region, and near Soan a

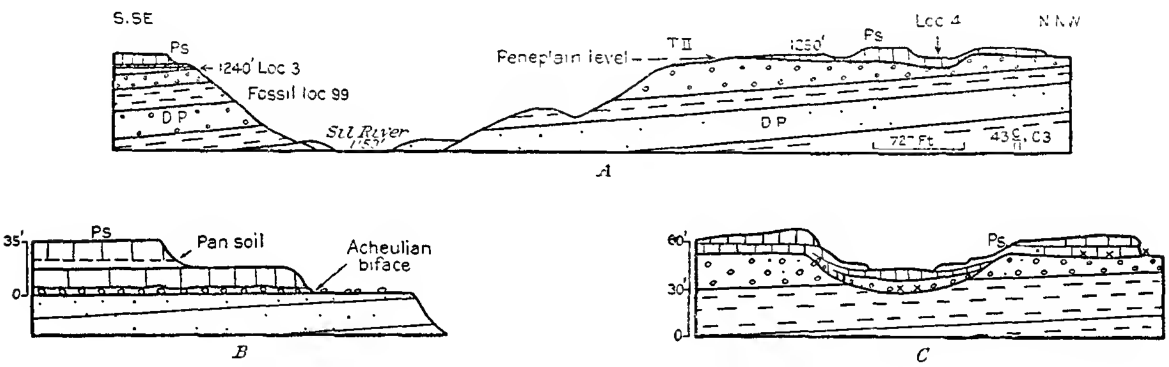


FIGURE 173.—*A*, Composite section 16, through right bank of Soan River below Chakri; *B*, *C*, Detailed sections at localities 3 and 4. Ps, Potwar silt; D.P., Dhok Pathan beds; T$_{II}$, terrace.

wide terrace level is cut into it 90 feet above the Sil River. There is no Boulder conglomerate, but on the high terrace (locality 3) was found a firmly cemented gravel, 4 to 6 feet thick, lying unconformably on Dhok Pathan beds and overlain by pinkish sand and silt of the Potwar zone. From it Dr. Teilhard extracted a perfect yet water-worn late Acheulian biface (pl. XXXI, *C*). Very likely this is at the same horizon as the Chauntra level of section 15 (fig. 172, *B*), but its position above the Soan is somewhat higher than we would expect, owing probably to the tributary nature of the drainage and to the greater resistance of the Pliocene conglomerate to the erosion of the post-Siwalik Soan River. The same section 16 yielded a site with early Soan pebble tools, the quartzite and trap pebbles being derived from the underlying Dhok Pathan beds (fig. 173, *A*, locality 4). Chipped pieces of quartzite were extracted from the basal gravel in an old gully fill below the loess; at another place flakes and cores were found at the base of a loess wall some 30 feet beneath the surface (fig. 173, *C*). Here the pebbles of the loess gravel are strongly patinated, but as the gravel is a redeposited Dhok Pathan conglomerate in which all fragments are deeply stained, it is possible that the patina was already acquired in Pliocene time.

On the left bank of the Soan about 3 miles south of Chakri, in the vicinity of Gila Kalan, the Boulder conglomerate overlies unconformably Dhok Pathan and older Upper Siwalik beds to a thickness of 50 feet (fig. 174). The surface of this conglomerate, which is composed of both limestone and metamorphic rocks, is planed and may well represent T2. It is buried under Potwar loessic silt, at the base of which we encountered a Soan workshop (section 17, fig. 174, *B*; pl. XXIX, 4). On the gravel surface and a few inches from the loess wall flakes were grouped around larger quartzite cores, and a few of them protruded, still in place, from the undisturbed loess (W, fig. 174, *B*). A fresh discoidal core was found in place at the place marked "i" in the figure, which appears at the horizon of the basal loess culture. At least three such occupation sites were found on the slopes of Pir Abdul hill, southeast of Gila Kalan. A few large but water-worn flakes of pre-Soan type were found on the gravel-strewn slopes below the loess (f, fig. 174, *B*). They are

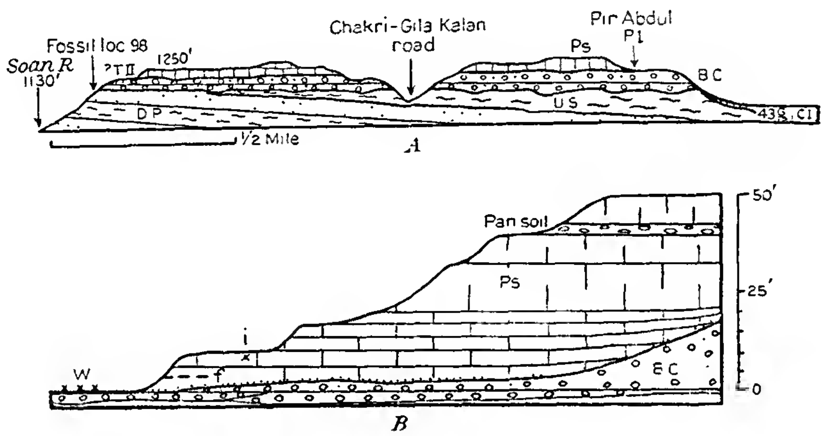


FIGURE 174.—*A*, Cross section through left bank of Soan Valley near Gila Kalan; *B*, Detailed section at Pir Abdul (section 17). TII, terrace; D.P., Dhok Pathan beds; Ps, Potwar silt; U.S., Upper Siwalik; B.C., Boulder conglomerate.

presumably derived from the Boulder conglomerate. The conglomerate is distinguished from the Pliocene gravel by its content of limestone detritus and the darker patina of its pebbles. Also it has preserved the dissected relief of preloessic time, which brings out sharply the angular unconformity with the Pliocene formation.

In addition to these sites there are no doubt countless others that did not come under observation. Especially the area between the Soan and Sil rivers, with its loess-covered Boulder conglomerate ridges, might yield many places of interest. One of them was found on the wayside at milestone 23 of the Chakri-Sihala road as illustrated by section 18 (fig. 175). Here again pre-Soan flakes were found in association with the conglomerate, clearly proving the stratigraphic value of these artifacts in differentiating between terrace gravel, Boulder conglomerate, and Pliocene conglomerates.

Farther downstream no Pleistocene terrace deposits are encountered, and we must assume that they have been eroded by the stream, which here flows in a much

narrower valley. At Dhok Pathan the slopes are rather steep, and the Middle Siwalik beds have been stripped of cover except for the peneplain surface, where loess and gravel veil the anticlinal structure. Here, on the road that leads across the divide between the Soan and Sil rivers, were found several sites beneath the loess. About 4 miles from Dhok Pathan one crosses a large patch of deeply stained gravel composed of well-rounded quartzite and igneous rocks. Its position is 320 feet above the Soan and therefore rather high for a Soan gravel, but as this is the peneplain level, we presume that the patch represents residual gravel of late Pliocene or early Pleistocene date, when this land surface underwent denudation. The pebbles are overlain by 5 to 10 feet of loess with 6 inches of small gravel at its base. This horizon yielded several late Soan tools, not all of which are stained. As these were made of the same hard pebbles that cover the surface, we conclude that patination is here of postloessic date. Indeed, the extraordinary thinness of the loess on this divide accounts for the deep patination of the surface gravels, which must have been exposed ever since the third glaciation, and in addition we may

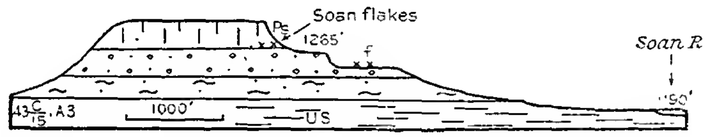


FIGURE 175.—Cross section 18, through right bank of Soan Valley near Sihala. Ps, Potwar silt; f, pre-Soan flakes; U.S., Upper Siwalik.

be sure that such patina could not have developed unless the climate since that time had been alternately wet and dry.

A second culture horizon was found in the upper few inches of the loess and on its surface. Here blades and keeled scrapers are conspicuous. Because of the uncertain origin of the upper loess layer these artifacts should not be pictured as representing a "loess culture," as we have no geologic proof of their age. If we want to give this horizon a definite date, we may at best refer it to late Pleistocene time, when there was redeposition of the loess. (See Paterson's report in section E below.)

A second site found previously by Lieutenant Todd, R. I. N., was described in the Punjab Gazeteer of 1932, and Paterson has discussed this industry in some detail (p. 310). Its position is 2 miles south of Pindi Gheb and three-quarters of a mile west of the Dhok Pathan road, some 200 feet north of a small tank. Here again the Middle Siwalik beds are capped by residual gravels, which are mantled by loessic silt toward the Sil River. The implements may be derived from the Potwar gravel, which thickens considerably down the slope, but here also we observed that artifacts are restricted to the vicinity of those outcrops where Middle Siwalik conglomerates have given rise to gravel deposits on the ancient land surface. At Pindi Gheb and all along the Sil River the Potwar loess thickens rapidly to over 200 feet, which proves once more the dependency of the silt accumulation on the post-Siwalik depressions.

EASTERN POTWAR

The culture-bearing Pleistocene is, however, not restricted to the Soan Valley but extends into neighboring drainage channels, of which the Kanshi River is one of the most important in the eastern Potwar (fig. 152). About 28 miles southeast of Rawalpindi the Grand Trunk Road crosses an anticlinal ridge in which Dhok Pathan beds are flanked by Upper Siwalik gray conglomerate sands and pink silt. The sands yielded a few indistinct and badly rolled mammal bones and seemed to belong to the same Upper Siwalik facies as is exposed northwest of Riwat, on the Soan. Section 19 (fig. 176) shows how this series is unconformably overlain by a coarse gravel and Potwar silt; the gravel, dipping slightly toward the valley, is also unconformable with the loessic beds. Thus the stratigraphic pattern with its two unconformities is typically developed, and we cannot hesitate to interpret the thick basal sand-silt series as the Tatrot and Pinjor zones, the coarse but thinly developed gravel as the Boulder conglomerate, and the overlying pinkish to yellow silt as Potwar loess.

The best exposures are found north of Gujar Khan, where the Hachiari Nullah cuts through the southeastern slope of the afore-mentioned ridge. Here loess

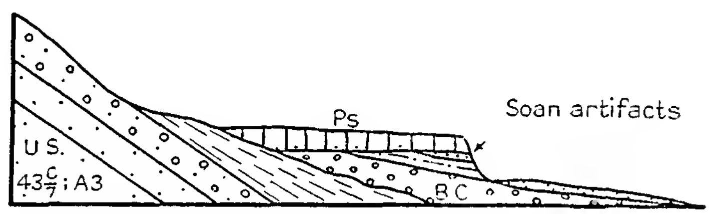


FIGURE 176.—Section 19, on eastern slope of ridge near Gujar Khan. U.S., Upper Siwalik; Ps, Potwar silt; B.C., Boulder conglomerate.

11 to 20 feet thick and with a thin basal gravel rests on a series of pinkish silt and gray sand, with coarse conglomerates at the base. The Potwar gravel at this point yielded several Soan flakes and cores, and the loess also contained a few thin quartzite flakes of the developed Soan type. The Potwar silt contains fragments of fossil turtle eggs and *Bulimus* but no fresh-water shells. The intermediate position of this site between the Soan and Jhelum rivers indicates that early man crossed the Potwar eastward in the direction of the Jhelum tract.

SUMMARY

The relationship between prehistory and geology in the Soan Valley can best be summarized by a general section (fig. 177).

The oldest industry found so far is represented by large crude flakes of quartzite and slate (pls. XXXI, A; XXXIII) which occur rarely in the upper portion of the Boulder conglomerate, of second glacial age. The oldest terrace gravels of T1, being of second interglacial origin, have been identified in one place only—namely, in a section southeast of Rawalpindi. Here they carry rolled early Acheulian hand axes (pl. XXXI, C) and flakes and indeterminate (? Abbevillian)

cores that reappear in more worn condition at Chauntra, where they seem to be derived from a third glacial terrace gravel. Early Soan tools are also found in T1 gravels, indicating a parallel development of this pebble industry, with early paleolithic hand axes. These axes were manufactured during the second interglacial period but were embedded and redeposited in third glacial and interglacial time.

The third glacial Potwar gravel (T2 and underlying T3) yielded the greater part of the "early Soan" implements as described by Paterson in section E below. This was subsequently buried by loessic silt to a depth exceeding 150 feet and later "exhumed" through erosion by that amount. At the beginning of the loess period the Soan people had developed a more specialized industry, called "late Soan" by Paterson, in which flake tools and cores predominate over pebble tools. In third interglacial time widespread erosion led to redeposition of all earlier industries in T3, but the presence of less rolled late Levallois flakes indicates

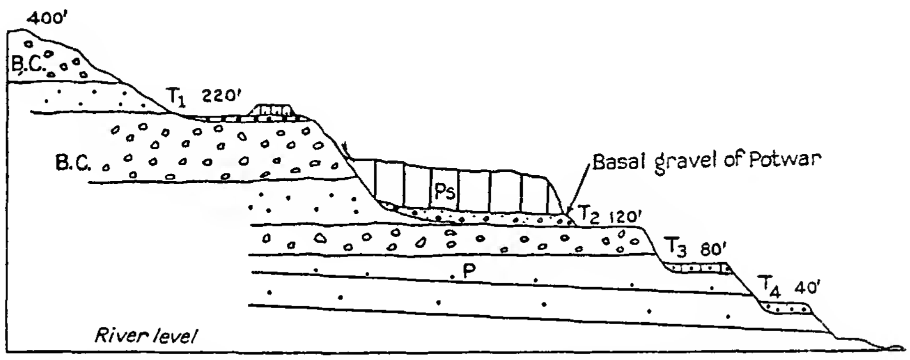


FIGURE 177.—General section through Soan terraces (T1, T2, etc.) above Chauntra. B.C., Boulder conglomerate; Ps, Potwar silt; P, paleolithic site.

the persistence of the late Soan tradition into this stage. In the following stage of aggradation (T4), which is broadly correlated with the fourth glacial soils formed on the peneplain surface and on higher terraces, occur tools presumably representing a late paleolithic industry (Pindi Gheb, Dhok Pathan).

C. PLEISTOCENE DEPOSITS OF THE SALT RANGE

Already we have said that the Upper Siwaliks appear in the form of thick basin fillings on the slopes of the Salt Range. At Tatrot, Bhaun, Jalalpur, Rohtas, and Dina (see fig. 152), the gray sandy conglomerate and pink silt series (Tatrot-Pinjor) make impressive piles of sedimentary rock 2,000 to 3,000 feet thick, disconformable on Middle or Lower Siwalik beds. Previously (De Terra and Teilhard, 1936) we have sketched some of these sections, each of which showed, when properly located in the Siwalik fold pattern, a breaking up of the late Pliocene relief in basins. Hence it is not surprising that the younger orogenic phase of post-Tatrot (or late Pinjor) date should have accentuated the relief in that it lifted the Salt Range high above both peneplain level and basins, thereby leading

to reorientation of drainage and sedimentation. This change from a planed surface with large depressions into an upland with entrenched rivers and new interstream divides is clearly reflected in the nature of those "ridge gravels" and loessic silts which we encountered in the Salt Range. We received the impression that the ridge gravels especially derived their constituents from near-by slopes, while the older Upper Siwalik beds received their supply by a more widespread denudation of a less elevated land surface. This feature is common to both Salt Range and Kala Chitta, but owing to the greater relief and width of the Salt Range the ridge gravels are here more conspicuous than elsewhere.

In the Tatrot Basin near Hasnot, for instance, ancient gravels are found in longitudinal valleys 120 feet above the present valley floors and some 300 feet below a planed surface which extends over Middle and older Upper Siwalik beds alike. A few miles east of Hasnot, near Bandhar (fig. 178), such a gravel is composed of subangular detritus of Nummulitic limestone, chert, pink granite, red quartzite, purple sandstone, and amphibolite, derived, no doubt, from the adjoining ridges built of Paleozoic and Eocene formations. There are boulders in this gravel which must have required strong river transport, such as is unthinkable under

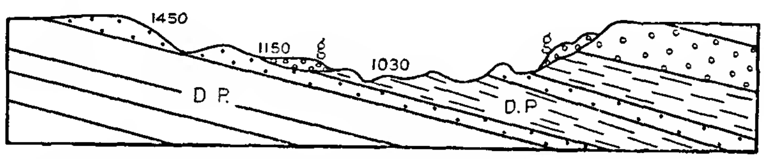


FIGURE 178.—"Ridge gravels" (g) as ancient valley fill in Salt Range near Bandhar. D.P., Dhok Pathan beds.

present climatic conditions. At Hasnot the Dhok Pathan clays and sandstone are disconformably overlain by a 7-foot conglomerate capped by 5 feet of brown silty sand reminiscent of the Potwar basal beds. Farther northwest, at a hamlet called Dhok Gul, half a mile upstream of a small valley, we found a few flakes of quartzite of late Soan type. The artifacts were found on a terrace remnant developed on weathered and stained Middle Siwalik sandstone, which is covered by a few feet of brown silt. Boulders of limestone and quartzite are here strewn over these dissected terraces, suggestive of a more denuded "ridge gravel" which was buried by the silt in a similar way to the deposit near Hasnot.

Patches of elevated limestone boulder gravel were found some 120 to 150 feet above the Bunha River 2½ miles northwest of Nathot. These bouldery gravels make residual hillocks on the peneplain and indicate widespread fluvial action at a time when the intermontane basin was filled with detritus from the northern rim of the Salt Range. This same process led to filling of the tributary valleys, causing deposition of 60 feet of ocherous half-cemented coarse limestone gravel overlain by 12 feet of brown-yellow silt and separated from it by a 2-foot limestone-pebble bed. The analogy of this stratigraphic pattern with that found in the Potwar needs no further comment, yet it suggests very strongly that the thick gravel represents a ridge-gravel facies of Boulder conglomerate age. In other

words, we have here in the central Salt Range the same succession of Pleistocene events as in the Soan—namely, a post-Tatrot planation and dissection, followed by a fluvial-fill stage with strong river action under wetter climatic conditions, succeeded in turn by a loessic phase.

An analogous sequence was observed upstream on the Bunha River near Nurpur, southeast of Duman, on the southern margin of the Potwar. Near the first ford beyond the Bunha Gorge superficially cemented gravel is overlain by loessic silt, its basal gravel resting on a deeply weathered terrace strewn with dark stained pebbles. Here, then, it becomes evident that the ridge gravel underwent long exposure before it was buried under loess.

Some 60 miles west-southwest from this place lies another intermontane basin—that of Naushahra—in which older Upper Siwalik beds rest against Paleozoic rocks in the south and are covered on the lower flank of the ridge by several hundred feet of bouldery limestone conglomerate.[1] On the corresponding northern rim of this basin the Upper Siwalik beds are faulted against the Eocene, the fault

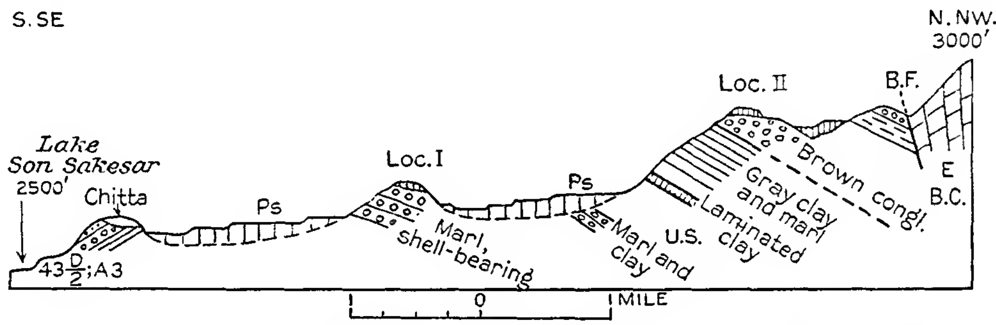


FIGURE 179.—General section through northern slope of Naushahra Basin near Chitta, Salt Range. Loc. I, II, ancient burials with funerary deposits; Ps, Potwar silt; U.S., Upper Siwalik; B.F., boundary fault; E, Eocene; B.C., Boulder conglomerate.

plane being somewhat tilted toward the north. At the west end of the Lake Son Sakesar Kahar the section (fig. 179) indicates dissection of this basin-filling prior to deposition of the loessic silt. As this area was described in a previous paper (Hawkes and De Terra, 1934), we need not discuss it any further except for a restatement of our views concerning the climatic phases as recorded in the Pleistocene beds.

At the time of my first visit, in 1932, it seemed as if three fluvial stages were documented here. On my second visit, in 1935, it was possible to assign the marl-bearing beds near Chitta to the older Upper Siwalik series and the overlying limestone conglomerates to a later stage separated from them by a disconformity. The marl and clay beds yielded fresh-water shells and diatoms. The diatoms, listed by Mr. Conger (see p. 261), suggest a wet temperate climate, which we are inclined to correlate with the first glaciation in the mountains or with the Tatrot age. The conglomerates, on the other hand, suggest a second "pluvial" phase in which denudation was rapid, leading to the accumulation of what we

[1] This section was previously described by De Terra and Teilhard (1936).

previously called ridge gravel of Boulder conglomerate age. These stages were separated from each other by a period of erosion, during which perhaps the equivalent of the Pinjor zone was removed. Then came the "long interpluvial" epoch, which we can now more clearly define as the time of dissection corresponding to the second interglacial stage in Kashmir. The Potwar loess, as we know now, was deposited during a valley fill stage which constitutes a third "pluvial," and to it we may perhaps ascribe the highest lake terrace of Son Sakesar Kahar. The second lake terrace and fans, which we ascribed to a late Pleistocene pluvial stage (Hawkes and de Terra, 1934, p. 13), would then represent our last phase of aggradation in the Potwar, presumably equivalent to the fourth glaciation. Hence our previous geologic interpretation of this isolated Pleistocene basin essentially corroborates our views on the physiographic cycle and proves that its various stages of sedimentation and erosion are manifested beyond the limits of the Potwar.

So far as prehistoric records are concerned, it should be noted that the chert artifacts of Chitta constitute a much later industry. Local excavations proved their association with fossil soils of postloessic age, and, in addition, typologically they bear no resemblance to any of the paleolithic industries found in the Soan and Indus regions.

D. ORIGIN AND CLIMATIC RECORD OF THE PLEISTOCENE IN THE NORTHWEST PUNJAB

SEDIMENTATION IN RELATION TO DIASTROPHISM AND CLIMATIC CHANGES

A summary of our observations on the Pleistocene of the nonglaciated tract could not fail to emphasize two outstanding features—the variety of facies changes as determined by the structural pattern of the compressed foreland belt and the cyclic character of sedimentation. The latter becomes especially striking if one contrasts the formational composition of the Pleistocene sequences found in the northwestern Punjab with the Quaternary of Kashmir.

Northwestern Punjab		Kashmir
T4 (terrace silt, sand).	Sedimentation (fluvial).	T4 (gravel, sand).
T3 (thin loam). Warping	Erosion.	T3 (thin loam).
Potwar loessic silt (T2) and gravel.	Sedimentation (eolian-fluvial, lacustrine).	Third moraines. T2 (boulder gravel). Massive silt in upper Indus Valley.
T1 (gravel). Folding	Erosion and redeposition of gravel.	T1 Upper Karewa silt.
Boulder conglomerate (boulder gravel, ridge gravel, plains drift). Folding	Sedimentation (fluvial and glacio-fluvial). Erosion.	Second moraines. Karewa gravel, sand.
Pinjor beds (silt, clay, sand).	Sedimentation (fluvial, lacustrine).	Lower Karewa lake beds (clay, silt).
Tatrot beds (conglomerate, sand, silt). Folding	Sedimentation (fluvial). Erosion.	Older fans (gravel, sand).
Middle Siwalik beds.		

It will be seen that a normal cycle of river sedimentation (gravel→sand→silt) was recorded only in the early Pleistocene, when the uplifting tendencies of the sub-Himalayan range slackened to such a degree that rivers became graded. Later on, uplift was more or less continuous, with varying intensity, which prevented the drainage from achieving any degree of maturity or, if such was temporarily established, its records were subsequently destroyed by erosion. Altogether there are four major phases of heavy sedimentation in the plains—one in each early and middle Pleistocene stage and two in the upper Pleistocene. Does this cyclic precipitation of coarse sediments reflect a fourfold diastrophic paroxysm, or did it depend on climatic cycles in which wetter and drier periods alternated, or was it the result of both structural and climatic agencies?

In order to clarify these questions it is well to keep in mind the peculiar situation in which the Pleistocene rivers were placed by simultaneous uplift and glaciation. If, as we had previously deduced, the sub-Himalayan tract was subjected to more or less continuous uplift with paroxysmal intervals (and only these were recorded in the structure), then a period of heavy glaciation must have arrested or at least lessened the supply of sediment in the source area of the streams, as most of it was ice-covered. It is this consideration that explains, in our opinion, the rapid accumulation of boulder fans, which owe their thickness to an accelerated release of detritus that had been locked up in moraines for a long time. In other words, at intervals glaciation retarded the effect of uplift on the sedimentation in the plains, which accounts for the fact that the thickest and coarsest formation at each valley outlet corresponds to the waning of the heaviest glaciation in the Himalayan tract. This erosion, then, had to perform the double task of removing the glacial detritus and catching up with the work that it had started prior to the second glaciation under the effect of the first uplift.

These conditions indicate the joint influence of climatic and tectonic agencies on plains sedimentation, but there are other considerations which make us believe in an even stronger effect of climate on the sedimentary cycle. If that cycle had been wholly dependent on cyclic uplift it must follow that the second paroxysm (post-Boulder conglomerate and pre-Potwar loess) should have left traces of heavy sedimentation somewhere in the depressions, as these were the collecting basins for the highland detritus. There is, however, little trace of it, but instead erosion prevailed throughout the second interglacial stage and finally led to terrace formation. It is as if the rivers at that time had just sufficient power to adjust their gradient to a new base of erosion; in fact, the decrease in their size is evident if we contrast the Boulder conglomerate in the Potwar with the meager gravels at the base of the loess. Indeed, between these stages lies an interval of general shrinkage of river action due not merely to shift of a Jhelum channel but to a decrease in water supply. The Potwar gravel marks again a phase of deposition by rivers and slope wash, and the loessic silt, as previously mentioned, equally testifies to fluvial action. In it we see another climatic phase—a "pluvial phase," if we like—which corresponds well to the third ice advance in Kashmir. On the basis of the terrace record alone it would seem that the last fill stage in the

Potwar (T_4) corresponds to the last glaciation, for the deposition of silt clearly was not continuous with that of the Potwar but was separated by an interval of erosion. It is probable that at this time pluvial conditions similar to those of the third wet stage prevailed in the plains, which would account for the heavy sedimentation of both eolian and fluviatile silt.

These considerations induce us to consider the pattern of the plains sequence as caused by the interference of two cyclic processes in which the climatic was superimposed on the structural and the geologic records have documented only those phases in which either one was free to manifest its dominant rôle, as exemplified by the Boulder conglomerate and Potwar stages. Both of these seem to have been true pluvial periods if by "pluvial" we mean a time span of the Pleistocene during which rainfall was locally much in excess of recent times. Under this definition the term "pluvial" must equally be extended to the Tatrot zone and the redeposited Potwar loam, and four wet periods result, each corresponding to a mountain glaciation. Such seems to be the meaning of our correlation so far as the periglacial and glacial areas are concerned. It remains to be seen whether in tropical India and southeastern Asia generally the Pleistocene sequences bear similar records.[1]

SOURCE OF UPPER SIWALIK DEPOSITS

As to the origin of the Quaternary deposits, we can now say that they are the local precipitates of an antecedent slope drainage and not derived, as Pascoe (1920*b*) and Pilgrim (1919) had speculated, from an "Indo-Brahm river." This hypothetical stream was supposed to have taken its origin in Upper Assam, flowing northwestward and then joining the Indus to make its exit to the Arabian Gulf. As first evidence in favor of this suggestion, Pascoe stated that a marine gulf "is naturally followed by a river" (meaning a large subsequent). Apart from the fact that this is hardly evidence but at best an assumption, it is known from better-explored foreland troughs north of the Alps and east of the Rocky Mountains that these were filled by action of transverse rivers descending from the upland. Such slope drainage, when repeatedly rejuvenated by intermittent uplift, is able to accumulate vast quantities of sediment, and as evidence is now at hand to prove how such Himalayan uplifts caused excessive sedimentation (Upper Siwalik beds), we can well dispense with Pascoe's first two arguments. Also we cannot quite see the evidence for a reversal of this hypothetical stream from a northwestern to a southeastern direction. To quote Pascoe, "Since the Siwalik outcrop is not continuous to the sea southeastward but continuous thereto northwestward and subsequently southward . . . it is reasonable to assume that the river followed this direction." To us it appears the other way around: because of the successive overlap of younger Siwalik zones on older beds in a northwestern direction the river might well have flowed southeastward, for that is the dip of the great foreland trough, as proved by the emergence of its floor in the northwestern Punjab. In

[1] Since this was written, the first author has had occasion to study the Pleistocene of Burma and Java. He came to the conclusion that there are four pluvials uniformly recorded in Burma, the geologic precipitates of which are in every respect similar to those described from northwest India.

other words, this zoning of Siwalik outcrops need not reflect a depositional arrangement but can equally well be explained by a tilting of the longitudinal trough axis toward the Gulf of Bengal. Theobald had already shown that the new Ganges alluvium in the delta overlaps upstream the older alluvium, and so in turn do the Upper Siwalik beds overlap the older Siwaliks, and these again lie on old Tertiary and Mesozoic rocks. That is the composition of a tilted syncline in which the present Ganges occupies the medial axis. As for the parallelism of such a longitudinal river valley with the configuration of the Himalayan belt on the north and peninsular India on the south, we believe this to be structural rather than erosional, and hence we cannot see in Pascoe's fourth and fifth points any evidence favorable to his hypothesis (see De Terra, 1934). As for the similarity of the recent river fauna between the Ganges and lower Indus, we do not think it necessary to postulate a common center of dispersal or origin, such as the "Indo-Brahm" may have offered, for the estuaries of these streams present the same habitat under similar climatic conditions and there are many such deltas on India's coast which promote intercoastal migrations.

More weighty is one of Pilgrim's observations. He claims that the direction of flow of this ancestral river can still be seen from the manner in which the present slope streams join the southeastward-flowing master rivers in an acute angle pointed toward the northwest. We must confess that we have no ready explanation for this phenomenon unless it is determined by a former deflection of the slope streams through foothill ridges of post-Siwalik age.

So far as factual data go it is evident from our description of the Pleistocene sedimentation that an Indo-Brahm river could not have existed in our region. The differentiation of facies, the local supply of sediment, the drainage pattern, and many other characteristics of Upper Siwalik and post-Siwalik formations are incompatible with such an assumption.

E. PREHISTORY OF THE POTWAR AND INDUS REGIONS

By T. T. Paterson

Attention was drawn to the presence of paleolithic implements in the Punjab by the publication of finds made by the Yale North India Expedition of 1932–33 (Hawkes and De Terra, 1934, p. 1). Prior to that time Lt. K. R. U. Todd (*idem*, p. 9) had discovered in 1930 a paleolithic site near Pindi Gheb, and Wadia (1928, pt. 2) noted the presence of early Stone Age tools on the banks of the Soan.

In 1935 more extensive collections were made along the Soan River and the Indus, and the value of such collections was enhanced by previous work on stratigraphic relationships to the Pleistocene glacial sequence of the northwest Himalaya. The following is an account of the collections so made. The text is divided into two parts, the first illustrating the general geologic background, and the second describing typologic variations of industries from different horizons. In order that the clarity of the sequence may not be obscured by too much detail regarding sites the system has been adopted of describing together those finds which are

typologically similar and come from the same horizon. Finds that come from the same horizon but differ in typology are described separately.

STRATIGRAPHY

There are two important areas—the Soan Basin, and the Indus River from Attock to the junction with the Soan. It was noted that the sites were congregated close to the river on terraces, suggesting that the river valleys afforded better hunting and habitable ground or more easy routes for travel.

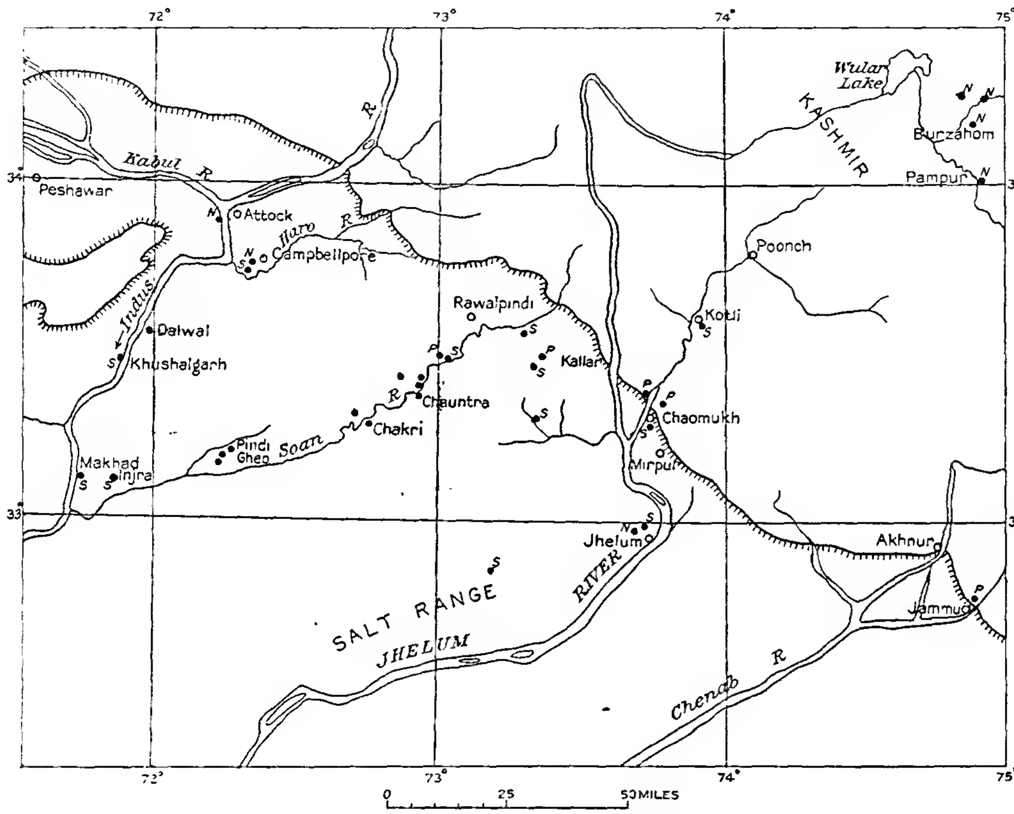


FIGURE 180.—Map showing distribution of prehistoric sites in the northwestern Punjab. Dentate line indicates mountain border. S, Soan industries; P, pre-Soan artifacts; N, neolithic sites.

On the banks of the Indus collections were made on the terraces at Dalwal, Khushalgarh, Makhad, and Injra (fig. 180). The accompanying section (fig. 181) shows the sequence at Makhad, close to the outlet of the Soan River. Here, just north of the point where the Indus breaks through the Salt Range, a large basin existed in early Pleistocene time, for the Tatrot-Pinjor series of basal conglomerates, green, brown, and yellow clay and pink marly silts, is over 500 feet thick. The bedding is slightly tilted to the west, but passes conformably upward, through sands, to the Boulder conglomerate of second glacial age, which has been reduced to a thickness of 250 feet. The conglomerate in places carries boulders as much as 2 feet in diameter, and is coarse and loose, weathering easily. In second inter-

glacial time this rock was eroded very deeply, leaving a terrace (T1) at 450 feet, with its surface covered with redistributed Boulder conglomerate, which in places became cemented together. This in turn was cut through during third glacial time, and a conglomerate as much as 30 feet in thickness was deposited. Here are found boulders, weathered deep brown and purple like those on T1, contrasting strongly with the "clean" conglomerate in which they are embedded. This conglomerate is covered by a thick layer of Potwar loesslike silt, which extends even on to T1 and forms the surface of T2 at 380 feet. T3, at 150 feet, was produced by fairly long erosion during third interglacial time and has a basal gravel sur-

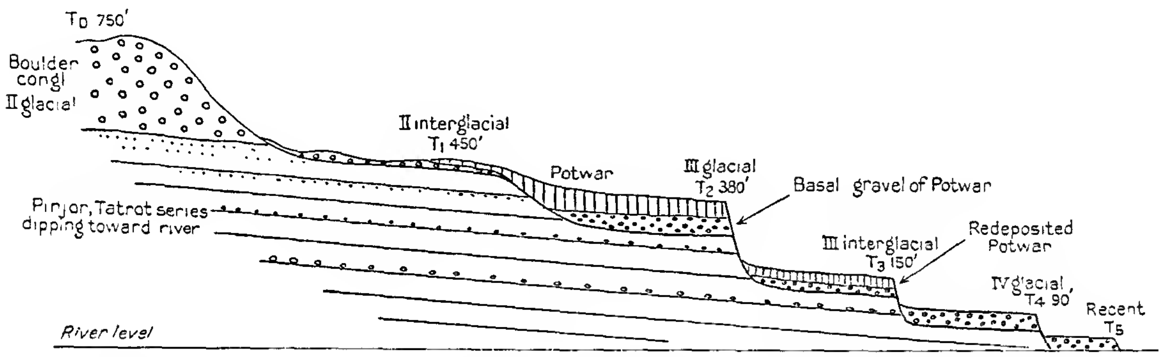


FIGURE 181.—Transverse section through Indus terraces (TD, T1, etc.) near confluence with Soan River.

mounted by redeposited Potwar. T4, at 90 feet, of fourth glacial age, is composed of gravel, and T5, of later than fourth glacial age, is still younger. T5 is low, 30 to 40 feet, and is sometimes inundated by flood waters of the river.

TYPOLOGY

In general, the typologic sequence shows that the earliest tools, large massive flakes with little retouch, occur in the Boulder conglomerate toward its top. They are rolled, which suggests that they were made while the conglomerate was still in process of deposition. During second interglacial time Acheulian types of hand axes appear. Unfortunately no site was found where the earlier types are in place, but rolled forms occur with fresh, late Acheulian tools of third glacial age; moreover, the Abbevillian types are much more heavily rolled than the early Acheulian. Some slightly rolled Middle Acheulian hand axes have been found in a gravel which is correlated with that on the terrace T1 of second interglacial age, and lately a site has been discovered where such tools have been found unworn.[1] Of the same second interglacial age is a series of pebble and flake tools discovered on the Indus terraces. The pebble tools are at first massive and crude but become progressively finer, and the associated flakes, Clactonian-like in appearance, approach proto-Levalloisian forms in the later stages.

Such flake tools seem to herald the appearance in third glacial conglomerates of a very pronounced flake assemblage with faceted flakes of Levallois character

[1] This site was discovered in 1937 by Mr. E. S. Pinfold on the Soan. The implements have reached Cambridge for examination, but too late to be included in these notes.

and appropriate cores, as well as simple Clactonian-like flakes and cores, and a small group of fine pebble tools of a kind which may have naturally developed from the pebble tools of second interglacial age. Evidences of this industry are found widespread along the Soan Valley, and, because of its easily recognizable, distinct, and characteristic assemblage, De Terra has given it the name "Soan industry."

Of an age perhaps somewhat later are tools excavated by Teilhard de Chardin and De Terra near Chauntra. Here late Acheulian hand axes in an unworn condition are associated with cores and flakes that are typologically similar to those of the Soan industry. Here also occur worn middle Acheulian bifaces and very worn Abbevillian types. The fresh tools are of importance, because they are typologically like those of a well-marked industry at a definite horizon in the terrace deposits of Madras.[1]

From the Potwar silt above have been recovered flakes and blades, many of them with faceted platforms. These forms have some resemblances to the late Levalloisian of Europe.

Near Dhok Pathan, on the Soan close to Pindi Gheb, was found a surface site of small flakes and pebble tools similar to those collected by Lieutenant Todd. The age of the terrace on which they are found is not known accurately, and the peculiar facies of the industry, with pebble tools predominating, does not permit a dating based on typology, though it can be said to be contemporary at least with the late Soan and may possibly be even later.

These several industries are described below in stratigraphic sequence.

From the Boulder conglomerate

Chaomukh (43 G/11[2]): From the Boulder conglomerate of the hill marked "1580," 3 miles northwest of Chaomukh, behind the farmhouse of Mohra Kanial.

Kallar (43 G/7): From the Boulder conglomerate of the hills 3½ miles northeast of Kallar, forming the western limit of the Doberan syncline.

Adial (43 C/15, C1): From second gravel layer of Boulder conglomerate above Adial.

Jammu: On road to Khanpur.

Malakpur (43 G/16, A3): From Boulder conglomerate ridge east of village.

From TD and T1 and rolled in later gravels

Khushalgarh (38 O/SE., ½-inch): From the terraces north of the railway on the right bank for 2 to 3 miles. North, on left bank, 10 miles, Rakh Jalwal. North, on left bank, 20 miles, opposite Shadipur.

Makhad and Injra (38 O/SE., ½-inch): From the Indus terraces between the railway station at Injra and Makhad, on the river.

Gariala, southeast of Attock at the outlet of the Haro River into the Indus: On the terraces north of the Haro.

The tools from the Boulder conglomerate (second glacial) are big flakes made from quartzite, all in a very worn condition, with large, plain, unfaceted striking platforms at angles mostly low, varying from 100° to 125°. The bulbs are flat, but the cones are well developed, some of them very large. The upper surface is

[1] Compare with description of the Attrampakkam industry on p. 329.

[2] Numbers in parentheses refer to maps of India Survey.

usually unflaked except for one or two small irregular scars. There is no secondary working on any but one specimen from Kallar (pl. XXXIII), where small flakes of later date have been struck from the main upper surface. The edges are often battered, whether by utilization or by natural agency it is impossible to determine.

On the Indus at Khushalgarh, Injra, and Makhad, a series of well-patinated tools, worn and otherwise, was found on the surfaces of TD and T1. Similarly patinated tools and boulders were found in a rolled state, in the gravels of T2. Therefore it can be assumed that implements from the surface of TD and T1 of this old patination are earlier than T2, and hence of second interglacial age, and, as T1 was formed during the later part of that stage, the time limits within which this series falls are still more closely defined. From Gariala a rolled cleaver of early form has been found in the gravels of T2.

The tools from the Indus region appear to constitute a fairly distinct group, which may conveniently be termed the early Soan in contrast to the Soan industry proper, which, along with later flake industries, may be termed the late Soan. The early Soan is much more crude and primitive than the late Soan, but both show a flake technique coupled with the consistent use of pebble tools. The early Soan tools differ in patination and state of wear and have been therefore divided into three groups, here termed A, B, and C. The earliest, A, is heavily patinated, deep brown or purple, and thoroughly worn. This worn condition may signify that the tools were manufactured at a time when active erosion of the terrace was still in progress. Group B is deeply patinated like A but not worn at all, and group C is less patinated and fairly fresh. From this last group comes a tool of quartzite which has corroded away where a skin of patination has not protected it. Such corrosion, occurring on the upper two terraces, has not been seen in later formations. The tools are made of varieties of quartzite, generally fine-grained, and of Panjal trap, easily recognizable by its greenish-gray patination color and its flake fracture, fine and smooth, compared with the coarseness of the quartzite. It is from the traprock that the finer tools and flakes are made, and regard was had to the fact that the difference in material will produce differences in appearance of the final tool, though made by people of equal skill.

The three groups are characterized by a variety of pebble chopping and scraping tools, associated with a comparatively small number of flakes, which however, tend to increase in the later groups, and, though a division based on state of preservation does not connote a definite stratigraphic sequence, yet there is a typologic developmental trend toward smaller and less crude forms of the various implement types.

These implement types may be divided into groups of pebble tools and flake tools.

The pebble tools are all struck from thoroughly rounded, water-worn pebbles and small boulders and may be subdivided as follows:

(*a*) Flat-based: These are portions of pebbles, one side flat or nearly so, produced by natural cleavage or artificial breaking. From this surface flakes are struck off steeply toward the upper rounded surface, resulting in strong working

edges, usually convex, sometimes straight, never concave. This flaking may be free, when the specimens can possibly be interpreted as cores, but often the presence of strong, rather small step flaking alone precludes this interpretation in favor of their being tools. The working edge may be continued all around the pebble or only partly around, and, depending on the original form of the pebble, the tools may be circular, boat-shaped, or oval. The edges often show signs of utilization, but it is difficult to determine for what purpose, chopping or scraping.

These flat-based tools may be more fully described individually.

(i) (pl. XXXIV, 1): A roughly oval pebble may be split crosswise, and the broken end crudely trimmed with coarse step or free flaking.

(ii) (pl. XXXIV, 4): A large elongated oval pebble with flat cleavage or flake surface on the lower side may have flakes struck upward from this direction along one side and sometimes around one roughly pointed end.

(iii) (pl. XXXIV, 2, 3): As in (ii) but flaked down both sides, or else more circular in shape and flaked all around. These types (ii and iii) have the flaking at a high angle to the flat base, often at 90° or nearly so.

(iv) (pl. XXXIV, 5): The flat base may be formed by one large or two smaller flake scars, and the upper surface is high and rounded. At one end two or three flakes are struck upward from the flat under surface at angles of 50° to 80°, forming a sort of short chopping edge.

(*b*) Rounded-pebble tools: Determined by the shape of the pebble, whether it is flattish oval or spheroidal, the flaking of the rounded tools varies, resulting in different forms. The flakes are struck from the original pebble surface, not from a flat cleavage or flake surface, which forms a much more suitable striking platform.

(i) (pl. XXXV, 1): Small spheroidal pebbles with a working edge formed by the intersection of two or three large flake scars struck alternately from each side, the second flake being struck from the platform formed by the first flake scar.

(ii) (pl. XXXV, 2–5): Flattish oval or circular pebbles are flaked up from one surface only, halfway around the periphery, the flaking being at an angle between 20° and 65° to the under surface. In one or two specimens there is flaking from the upper surface toward the under surface as well, but along the opposite edge. In the later stages of development the flaking is sometimes extended all around the periphery.

(iii) (pl. XXXV, 6): A flat, elongated oval pebble is broken along its axis and the broken side chipped to an edge by flakes struck from each surface.

(iv) (pl. XXXV, 7): A flat oval pebble is flaked from one surface at one end on opposite sides so as to produce a point. The less pointed specimens of this type approach *b* (ii).

The flaking of most of these pebbles has produced scars which are large, fairly regular, rather deep, and often ending in a distinct step. These large flake scars are frequently broken into by smaller and rather crude step flaking along the edge.

It should be noted that many of the specimens included in the above-described types were probably intended as cores in the first instance, especially types *a* (ii), (iii), and (iv) and *b* (i) and (iii), but have undoubtedly been used as tools, for otherwise there would have been no necessity for the crude step flaking along the edge, which occurs in so many specimens. The undoubted cores are large discoidal forms, sometimes elongated in shape, with flakes struck off alternately

from each surface (pl. XXXVI). The development in cores is toward smaller and neater forms.

Early Soan Sequence

Early Soan A.—Deeply patinated, brown and purple, and heavily worn. There are not enough specimens of this age to demonstrate which type of tool predominates, but the forms *a* (i) and (ii) and *b* (i), (ii), (iii), and (iv) occur. There are several crude discoidal cores, only three or four flakes being removed. One large chopperlike core has a pebble butt and two flakes struck off on each surface. No flakes were found.

Early Soan B.—Deeply patinated like A, but unworn. All types of pebble tools occur except *b* (i). There are several roughly discoidal cores, one very large. These cores are fairly neat, flaked more or less all around on one or both sides, usually alternately. There is one large chopperlike core.

The associated flakes (pl. XXXVII, 1–4, 6) have unfaceted platforms, the angle varying between 95° and 130°. Occasionally the platform is placed at an angle to the axis of the flake. In some specimens the bulb is more or less totally removed by an éraillure; in some the bulb is nearly flat, and in others it is strongly convex. There is little retouch, but in some specimens chipping resulting from utilization simulates coarse retouch and may possibly be so. The primary flaking of the upper surface is crude on the whole, often with part of the original pebble surface remaining, but in some few specimens it is much more regular. Step flaking is common. The general impression is that this industry, apart from the great number of pebble tools, has resemblances to the early Clactonian of Europe.

Early Soan C.—Less patinated, light brown; only slightly worn or not at all. All types of pebble tools occur, but type *b* (ii) is by far the most common. A probable development from this type is the disk, flaked all over one surface. A new type, *b* (v), appears at this stage and becomes much more common in the late Soan. It is a "side chopper," roughly oval in shape, with a pebble butt and two or three large flakes struck off on each side of the working edge, which may be straight or convex and occasionally has some secondary working. It is perhaps a developed form of *b* (i). Some of the specimens of form *b* (v) show no signs of utilization and may be regarded as cores alone.

Otherwise the undoubted cores are of the discoidal type with alternate lateral flaking, often with a patch of "cortex" remaining in the center of one or both surfaces. These discoidal cores resemble the Clactonian forms and also the early Levalloisian. However, another type of core appears, which is more nearly akin to other Levalloisian forms—flat, with under surface cortex and striking platforms simply prepared at each end by the removal of two or three small flakes (pl. XXXVIII, 3, 5, 6).

Correspondingly, there are two kinds of flakes—those with high-angled plain platforms having the same general characteristics as early Soan B, but flatter and neater on the whole and with a greater amount of primary flaking (pl. XXXVII, 5; pl. XXXVIII, 1, 4); and those, rather fewer in number, with low-angled, simply

faceted platforms (pl. XXXVIII, 2). There are no definite signs of retouch but distinct signs of utilization.

Other second interglacial industries.—Other tools of second interglacial age have been found in the Soan Valley. However, the only definite proof that they are of this age is that they occur, rolled, in gravels of the third glacial phase. These tools comprise hand axes, cores, and flakes. Some of the hand axes are very much rolled and are probably Abbevillian or Lower Acheulian. They have thick pebble butts and large crude flaking, showing in some specimens a rudimentary step technique. There are one or two rolled flakes, with plain platforms and primary flaking of a very primitive nature.

A less rolled group can be ascribed on typologic grounds to the Middle Acheulian, having neater step flaking and a more regular outline. They are mostly fairly long and narrow, with one end slightly more pointed than the other. Some are made on rather thick flakes, with large plain platforms. There are one or two rolled cleavers of primitive form. Many of the cores are pebbles roughly flaked at random; others have more regular flaking and are mostly of the discoidal type. There are a few flakes which show typical Acheulian technique, with plain platforms and parallel primary flaking. One or two of these are crudely retouched.

These last-mentioned tools came from the surface 220 feet above the Soan River shown in figure 163.

Late Soan Sequence

The "Soan industry" is of third glacial age and constitutes the earlier, A, of the two industries which are classed as the late Soan, the later, B, coming from the Potwar clay above.

Late Soan A.—In the late Soan A industry still survive a variety of pebble tools, which, however, are associated with a far greater number of flake tools and cores, the flake element becoming distinctly Levalloisian in technique, with the simpler forms of plain, high-angled platform flakes still prominent. Some of the specimens are worn, which may indicate that they were made at a time of active deposition of the gravel, but even when separated out they do not show any typologic differences from those that are not worn.

Pebble tools: The form *b* (v) of the early Soan is very common, made on a roughly oval pebble, with untouched butt along one side and flaking along the opposite side, either from one surface alone or alternately from each surface to produce a wavy edge, which may be straight or convex. Another common form is akin to *b* (i), with one or two flakes struck from each surface at one end. Type *b* (ii) also appears, and there are several like *a* (iii), though smaller and circular, with the flat base a flake scar. One specimen is made on a flake.

There is a new and rather peculiar type (pl. XL, 3). A flat base is produced by breaking off at an oblique angle one end of a small ovoid pebble; two or more flakes are then struck upward from the under surface on the side that makes an acute angle with the base. It ranges from 1½ to 3½ inches in height, and the oval base from 1¾ by 1½ inches to 3½ by 2 inches. There is in some specimens

a little secondary working at the edge. This tool may be a specialized derivative of early Soan type *a* (iv).

Cores: There are many forms of cores.

(i) (pl. XXXIX, 1–3, 5): A flat pebble has small flakes struck off at one or both ends and sides, and the scars are used as platforms for the removal of flakes from the upper surface, the lower remaining untouched. The flakes are usually removed from opposite ends, so producing an oblong shape. In most specimens the flake scar platform is not faceted, though, in a primitive fashion, prepared, but in some it is faceted in Levalloisian fashion (pl. XXXIX, 5). The angle of the platform of the resultant flake is usually fairly high. There are variations of this type, as for instance those on thicker pebbles, with consequently broader platforms.

(ii) (pl. XXXIX, 4): Similar to the form described above are cores of subtriangular shape, from which only one triangular flake, comprising most of the previously trimmed upper surface, has been removed.

(iii) (pl. XXXIX, 6): A circular core with a flat base of flake scars has a conical upper surface, sometimes terminating in a central patch of cortex. This upper surface is produced by striking flakes (which may in themselves be large enough to utilize) from the lower surface, but their removal produces faceted platforms suitable for taking flakes off the lower surface itself. Such a process, alternately striking from the upper and lower surfaces, was continued in some specimens until the core was too small for further use.

(iv) (pl. XL, 2, 4–6): The discoidal core is common. Flattened circular pebbles are flaked all around the periphery alternately from each surface, resulting in a roughly diamond-shaped cross section, with a more or less wavy edge. Occasionally, and especially in the larger cores, a patch of cortex may be left in the center of one or both surfaces; certain forms may thus approach type (iii). The more simple forms are Clactonian in appearance, and the flakes from them have plain high-angled striking platforms. The flaking is often very large and irregular, resulting sometimes in a more oblong core. In these irregular examples there is no secondary flaking, as there sometimes is on the regular type, to even the edge, so that the core may be used as a chopper, or maybe as a slingstone.

(v) (pl. XL, 1): There are a few specimens where flat pebbles have been split and the fractured surfaces alone have had flakes struck from them, producing evenly convex surfaces and so meriting the name "turtle-back type."

(vi) (pl. XL, 7): The chopper type of core is triangular in cross section, with a thick pebble butt and flaked on each side of the working edge. Some specimens show signs of secondary working along the edge, or else of utilization. Whether these were made purposely as side choppers or scrapers or are merely utilized cores is not certain.

The vast majority of the cores, which seemed to be, on the sites, more common than the number of flakes justified, are of the types (i), (iii), (iv), and (vi), or are variations of one or other of these.

Flakes: The number of flakes retouched to form tools is comparatively small, which may be due to the quartzite being so hard that retouch of the edge of a flake is unnecessary. Of those that are retouched about half are "pebble flakes"—that is, their upper surfaces are cortex; and the platform, too, is usually pebble surface, more rarely a flake scar. The forms these retouched flakes take are roughly oval or circular, with very steep, fine free trimming, sometimes all around the edge (pl. XLI, 4, 5). There are a few side scrapers on flakes struck from prepared cores, and these are larger and generally triangular in shape. The non-retouched flakes are of all shapes and sizes, and a few blades appear. Many of the flakes show a technique akin to the Levalloisian, often with neatly faceted

platforms, and with regular primary flaking, usually convergent (pl. XLI, 1, 3, 9, 10, 12). Sometimes there is a large scar covering most of the upper surface of the flake (pl. XLI, 2, 7, 11).

Late Soan B.—Late Soan B is found in the Potwar silt not far above the gravel of third glacial age. The tools are exceedingly fresh and unworn, but there are no signs of wind abrasion, as might be expected from their occurrence in a wind-blown deposit.

Cores are of types (i) (pl. XLII, 4) and (iii) of late Soan A. One core retains cortex completely over one surface, and two others are roughly oblong, flaked across their length. Another is subtriangular in cross section and flaked upward on each side from a flat under surface.

Flakes (pl. XLII, 1–3, 5–7): Almost half of the flakes have faceted platforms, but none show any signs of retouch, and only a few of utilization. They are mostly blades or elongated flakes, with a few triangular or oval, and most of them have large primary flaking on the upper surface. These flakes have certain resemblances to the late Levalloisian of Europe.

The Chauntra Industry

The specimens representing the Chauntra industry were excavated from a gravel that may be of third interglacial age. They consist of a mixture of Acheulian and Soan elements, and can be divided into three groups on the basis of their state of preservation.

(*a*) The oldest is very worn and comprises one or two hand axes of very primitive type, probably Abbevillian; cores, which mostly take the form of large pebbles crudely struck at random; and one or two massive flakes, with large plain platforms, resembling those from the Boulder conglomerate. There are also a few smaller, rather nondescript flakes.

(*b*) The next group is less worn, and here the hand axes, with less crude flaking and a more regular outline, indicate a typologic age of lower to middle Acheulian.

(*c*) The fresh, unrolled specimens include some late Acheulian hand axes, cordate (pl. XLIII, 4), pyriform, and pointed ovate. One of the pointed ovate type is made on a flake, the upper surface being neatly trimmed with step flaking, except near the butt end, where the original pebble surface remains. The flake surface is left untouched, except for a little trimming near the edge (pl. XLIII, 5). The other specimens, though neatly and regularly flaked, have less delicate trimming. These hand axes are associated with rough discoidal cores and small fine cores of type (iii) of the late Soan (pl. XLIII, 3). One or two of the flakes belonging to this group have faceted platforms, and some are retouched; most have fairly regular convergent primary flaking (pl. XLIII, 1, 2). One blade only was found (pl. XLIII, 6).

Other Industries

At Dhok Pathan, a few miles from Pindi Gheb, a site was discovered on a terrace of unknown age. This site yielded pebble tools and flakes similar to those of Pindi Gheb. By the great kindness of Lt. K. R. U. Todd, who discovered the

Pindi Gheb site, the specimens from that site were placed at the disposal of the expedition for examination.[1] It has been found that the subdivision by Lieutenant Todd into early and late groups on grounds of patination cannot hold, for the early sandy-colored patination (Hawkes and De Terra, 1934, p. 9) is confined to specimens made of traprock, whereas the darker-colored tools are quartzite, which does not patinate in the same fashion.

The small group of pebble tools includes specimens which are identical except in size, being very much smaller, with types *a* (i), *a* (iii), *a* (iv), and *b* (ii), of the early Soan (pl. XLIV, 5, cf. pl. XXXIV, 1; pl. XLIV, 6, cf. pl. XXXIV, 2; pl. XLIV, 7, cf. pl. XXXIV, 3; pl. XLIV, 8, cf. pl. XXXV, 4). A new type of implement is a kind of awl, made on a small oval pebble flaked on both surfaces at one end to form a sharp point (pl. XLIV, 9). The cores are all small. Some are of the discoidal type, flaked alternately on each surface (pl. XLIV, 1). Others are small pebbles with flakes struck off at random on one surface only (pl. XLIV, 4). The flakes are rather similar to those of late Soan A, and have both convergent and parallel primary flaking, the latter predominating (pl. XLIV, 3). A few are retouched, one in particular, a steep scraper, having very fine trimming (pl. XLIV, 2). Faceting of the platform is rare.

The age of this series is uncertain, but to judge from typology and the state of preservation, it is undoubtedly fairly late and must be at the earliest contemporary with the late Soan, possibly later, perhaps even of fourth glacial age. It can best be regarded as representing a late, localized industry of peculiar facies, showing marked similarities, in a greatly developed form, to the early Soan industries of the Indus region.

CONCLUSIONS

The presence of large numbers of pebble tools and of cores made on small pebbles is one of the most outstanding features of the prehistoric cultures of the Punjab. This peculiarity can doubtless be explained by the fact that these pebbles were the only available source of raw material. The original shape of the pebbles themselves must have suggested certain forms of cores and implements. Thus, flat, round, or oval pebbles were used to a great extent, and the flaking of these on one surface, along one side or end, to form a working edge seems to be a fairly natural procedure. Of particular interest, too, are the thicker quartzite pebbles with a natural cleavage fracture, which provides a suitable platform for striking off flakes for utilization. The resulting steep-sided cores seem to have been often further trimmed along the edge, forming tools that could be put to various uses.

Just as in the Abbevillian-Acheulian cultures there is an evolutionary trend toward finer and neater forms of hand axes, so in the Soan pebble tools there can be traced a development toward smaller and more finely made types.

The Soan flake industries, too, provide an excellent example of the evolution of a flake culture in a small area. In the early stages the flakes are crude and

[1] The Pindi Gheb specimens are now housed in the University Museum of Archaeology and Anthropology, Cambridge, England.

simple, often rather Clactonian-like in appearance, with primary flaking of a very haphazard nature. In the late Soan, alongside the simple forms, there are other flakes, showing a development in technique, with much more regular primary flaking and often with faceted platforms, denoting careful preparation of the core in a manner reminiscent of the Levalloisian. Retouch, when necessary for the type of flake implement required, is much finer, but with the improvement in technique flakes and blades were produced with so fine and regular an edge that retouch was rarely needed.

It is interesting to note the parallel development in the Punjab of the Soan flake and pebble industries, alongside the Abbevillian-Acheulian complex. So far, these two entirely distinct cultures have been found in contact at one site only, Chauntra, where hand axes of late Acheulian type are associated with cores and flakes of late Soan age. The specimens from this site are, unfortunately, too few for the results of this contact to be determined.

Further work is being carried out on new finds from the Punjab and the Madras paleolithic industries. Until this work is completed, it would be useless to attempt correlations or comparisons between northern and southern India.

PART III. THE PLEISTOCENE IN THE NARBADA VALLEY OF CENTRAL INDIA

Although the distance between the Siwalik Hills and central India is considerable (600 miles), it is nevertheless true that anyone interested in the Pleistocene of India could proceed southward by stages without ever completely leaving contact with the records of this period. To be sure, little is known of them. Patches of fossiliferous middle Pleistocene in the Jamna Valley and near Mirzapur lie in a wide expanse of ancient planed land on which the so-called "cotton soil" or regur is often enough the only deposit that can testify to a wetter Pleistocene climate. Laterite gravels have hardly been recorded from this region, and yet they must exist, to judge from their presence in the Narbada Valley. Very little indeed is known of the younger surface deposits on the northern rim of the ancient Indian land mass, and here lies a field of investigation important for the geologist and prehistorian alike. Its intermediate position between the glaciated highland and the tropical belt, between the mobile Himalayas and the Indian land block, arouses our hopes that here may one day be worked out solutions for climatologic and tectonic problems of first importance. In fact, such a traverse might provide us with many data that would clarify our views on pluvial and interpluvial periods and on the structural relations of the Indian land mass to the Himalayan belt.

Here no attempt will be made to approach this subject with as wide a scope as such an investigation would demand, first, because it was not contemplated, and second, 2 weeks allowed just sufficient time for making a brief survey of one valley portion. The Narbada region was one of the most accessible and promising valleys in peninsular India, especially in view of its wealth of Pleistocene vertebrate fossils. Paleoliths had also been reported from this area, and hence we were tempted to see how the peninsular Pleistocene could compare with that of the Himalayan Hills.

Our investigations were made between Hoshangabad and Narsinghpur, in the Central Provinces, and most of the localities can be visited from either of these railroad stations within an hour or less of walking or riding distance. It was here that, under Medlicott's directorship, W. Theobald (1860) had studied the Pleistocene sequence. At his time the beds were considered of Pliocene age, and it is only through Pilgrim's researches (1905) that we know of their younger stratigraphic position. The prehistoric records were restricted to one hand ax in the reddish clay of Theobald's "upper group" and to several surface finds of flake stones. There is also a later record by Theobald (1881, p. 122) of a human cranium preserved and then lost in the museum of the Asiatic Society of Bengal, supposed to have come from a conglomerate bone bed. Theobald listed it as *Homo sapiens;* hence it seems more likely that it was collected from younger deposits, perhaps from the cotton soil, in which we found late paleolithic tools. With Theobald's division into "lower" and "upper" groups we can only agree, but the upper group, in our view, begins with a basal gravel which Theobald associated with his lower group. No new finds of mammals were made, but we succeeded in proving the association of early paleolithic hand-ax and flake industries with a middle Pleisto-

cene type of fauna (*Elephas antiquus* [*namadicus*]), thereby supplementing our data won in northwest India, where such correlation had to be based on other than paleontologic evidence.

River silt and cotton soil give the Narbada Valley its fertile aspect and promote agriculture, whose products the river helps to trade (pl. XXX, 1). In prehistoric times, however, man was primarily a hunter of big game, living either on the open terraces of the stream or on promontories that rose above the wilderness, which must have teemed with life. Even in our days this region constitutes one of the great hunting grounds of India; its forests and thickets are the abode of large cats, bear, gaur, deer, and black buck, and the river teems with edible fish and crocodiles. This fauna is essentially indigenous, and many of its ancestors lie buried in the Pleistocene river drift in association with other mammals such as elephant, hippopotamus, horse, and rhinoceros, which enriched the pursuit of big game for paleolithic man. Indeed, here he must have been in his element, living on the edge of jungle-clad hills and on the very route which migratory herds of ruminants might

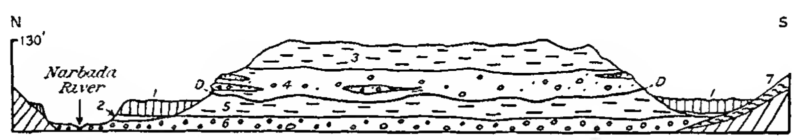


FIGURE 182.—Composite transverse section through Narbada Valley near Narsinghpur. 1, cotton soil; 2, basal gravel of cotton soil; 3, 4, upper group with pink concretionary clay (3) and upper gravel and sand (4); 5, 6, lower group with red concretionary clay (5) and basal conglomerate (6); 7, laterite; D, disconformity between upper and lower groups.

have taken to gain the northern plains in periods of drought. Considering also that the stream itself was firmly embanked between the foothills of the Vindhya and Sotpura ranges, depositing its drift regularly over long periods, we can expect a fairly complete geologic record.

A. GEOLOGY OF THE AREA

The Narbada Valley, between Hoshangabad and Narsinghpur, is 7 to 18 miles wide and underlain by a composite series of silt, sand, and gravel, of which some 130 feet is exposed in this area (fig. 182). In other regions, such as Sukakheri, borings have disclosed that the ancient alluvium is almost 500 feet thick, and at that depth no bedrock was encountered. Therefore, the upper valley portion as a whole coincides with a deep rock basin, which Vredenburg (1906) explained by an early Pleistocene warping along a northeast-southwest axis that crosses the valley some 65 miles downstream from our region. The river has entrenched its meandering course by 70 to 80 feet and erodes laterally more freely wherever it has reached bedrock, as at Hoshangabad (pl. XXX, 2). In this ancient alluvium we can recognize three sedimentary phases—the lower and upper groups and the cotton soil or regur. The lower group contains the middle Pleistocene fauna mentioned below and most of the early paleolithic tools. In addition, as Oldham

(1893*a*) pointed out, laterite gravel and laterite soil underlie the three groups, and these constitute, in our opinion, a major stage, bringing the total number of divisions to four. Between them we find three disconformities, testifying to three long periods of erosion.

NARBADA LATERITE

Beneath the ossiferous basal gravels with *Hexaprotodon*, *Equus*, and *Bos*, as exposed at Hoshangabad, there appears at Tugaria, 2 miles south of the river (fig. 183), beneath a few feet of yellow-brownish silt, a thick deposit of laterite.

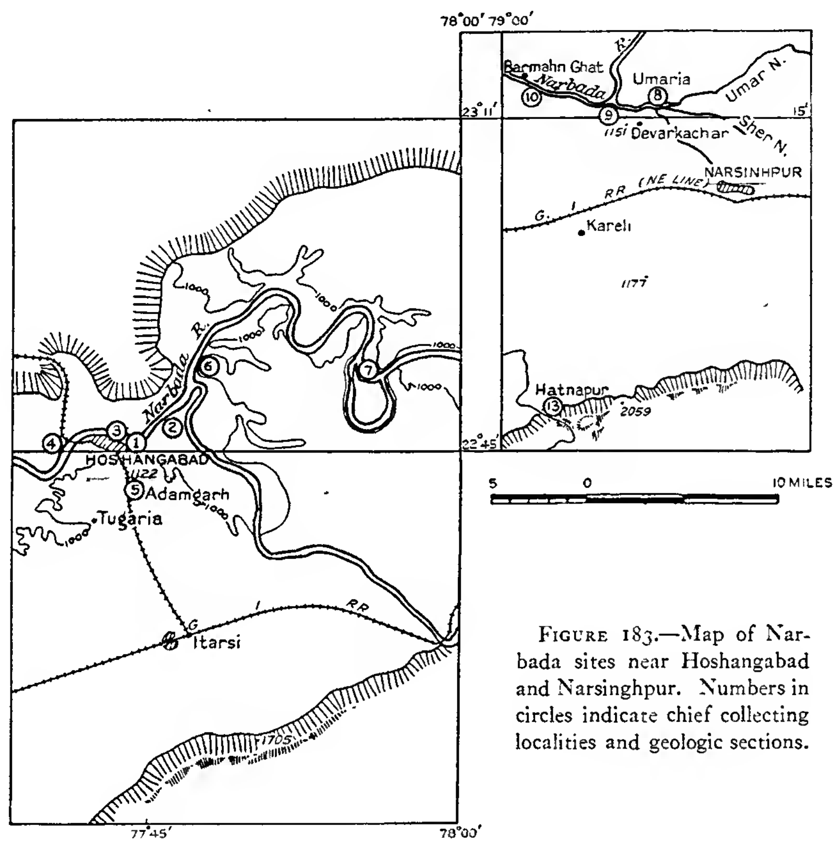


FIGURE 183.—Map of Narbada sites near Hoshangabad and Narsinghpur. Numbers in circles indicate chief collecting localities and geologic sections.

This deposit exceeds 30 feet in thickness and is charged with concretionary lumps of silicified hematitelike rock and decomposed boulders of trap. This solid layer is capped by a laterite gravel, which fills its surface irregularities in the manner of a rewashed or eluvial soil. Farther upstream, between Jubbulpore and Harda, such gravels, according to Oldham, underlie a cemented conglomerate, presumably belonging to the middle Pleistocene Narbada series. The structure and lithology of the main laterite indicate lateritization of Deccan trap (or a fan composed of trap boulders) preceding deposition of river drift and followed by erosion. The river drift apparently lies in a channel cut into the earlier laterite formation, and the thinness of its gravel cap suggests that during an intermediate period of erosion the laterite was extensively denuded. This might account for the absence of

laterite pebbles in the younger drift and would also indicate that lateritization terminated in this region at a time prior to the deposition of the lower Narbada zone.

This fact tends to illuminate somewhat the age of the laterite in central India, inasmuch as such deposits do not form nowadays, nor are they found in the ancient alluvium. From this we conclude that the laterite must antedate the stage of the ossiferous beds, when atmospheric agencies were more tropical and more like those now encountered on the west coast and in southern India. In other words, the climate hereabouts had attained its present dry-tropical character at the time of *Elephas namadicus* and of early paleolithic man, and it is not impossible that the first human settlement of the Narbada tract was somehow connected with this climatic change.

LOWER NARBADA GROUP

The basal beds begin with a coarse cemented conglomerate with intercalated layers of micaceous gray sand and pink silt, which rest at Hoshangabad upon bedrock (pl. XXX, 2; fig. 182, 6). The thickness ranges from place to place between 3 and 11 feet. Theobald (1860, p. 282) mentioned large boulders and *Elephas* from a place 17 miles above Sagwan Ghat, and at locality 4 we found *Hexaprotodon namadicus* and *Bos* sp. in these beds. At places the sandy layers are crowded with fossil shells of *Unio* and *Corbicula*, genera which still live in the stream. Undoubtedly, the so-called Narbada mammal fauna begins at the very base of the group, and so do the remains of ancient man. At localities 1, 2, 3, and 11 we collected and chiseled out from the conglomerate, large flakes with prominent bulbs, reminiscent of the pre-Soan industry of the Boulder conglomerate zone, also Abbevillian hand axes and Acheulian tools, as well as cores, most of which were heavily rolled. We found at locality 11, however, one Acheulian cleaver of amber-colored mottled flint with sharp edges, which appeared superficially embedded in the basal gravel on the edge of the river bank.

Conformable on this gravel is a red silty clay with lime concretions (fig. 182, 5). At Hoshangabad it measures 25 feet; farther upstream, near Narsinghpur, it is 32 feet thick. Thin bands of marl and lamination indicate a sluggish-water deposit, and this explains to a certain extent the mixture of fresh-water and land shells and the dearth of fossil bones. Theobald had claimed absence of stratification for these beds and thought of them as lake beds, but the faint banding in the concretionary layers and the presence of a few lenses of fine sand argue rather for a late stage of fluvial aggradation during which the river moved sluggishly across a wide flood plain. Besides its load of silt kept in suspension, eolian drift probably added to the accumulation of fine sediment, which at places is very reminiscent of the Pinjor or even of the reddish variety of Potwar silt, as will be shown below. In this respect it is noteworthy that the only land gastropod, *Bulimus insularis* Eh., was found restricted to the red clay. From this clay were extracted, especially at locality 6, several unrolled flakes and a fresh Acheulian biface (pl. XXXII, B).

Considering that the lower group had yielded both unworn and rolled Acheulian tools in association with heavily rolled Abbevillian hand axes and flakes, it would

seem that the manufacture of the Acheulian tools was contemporaneous with the deposition of these beds.

UPPER NARBADA GROUP

The disconformity that separates the two Narbada groups is clearly exposed wherever they are found in contact. The red concretionary clay exhibits an irregular surface marked by channels which are filled with gravel or sand of gray coloring (pl. XXX, 3). At locality 9 this surface is strewn with subangular blocks of slightly cemented sand lying in a loose matrix. At such places mammalian bones are concentrated, and entire skulls of *Bos namadicus* and *Bubalus palaeindicus*, as well as jaws of *Elephas namadicus*, testify to the accumulation of skeletal remains on an ancient land surface and lowering of the river level. The river no doubt still existed, but it must have cut a more fixed channel, whereby the ancient drift was exposed to subaerial denudation more strongly than before. Hence this surface may well represent a terrace level that was subsequently submerged under younger drift, though its remnants may still exist on the hill flanks, which did not come under observation. If this plane of disconformity was at one time a dry valley flat, it is obvious that the mammals whose bones were found in the gravels of the upper group may actually have lived at the end of the earlier phase of aggradation—a consideration which is borne out by the fact that the richest bone bed was found at the base of the upper group. At a time when the river was once more heightening its own channel and its small tributaries were charged with detritus from the valley flanks, the skeletal remains were washed together and embedded in the upper gravel.

This river teemed with invertebrate life, as testified by shell banks which have yielded ten species of gastropods and four species of clams, of which all except one are fresh-water forms, and all belong to living types.

Theobald (1860, p. 284) pointed out that there is a difference both in size and in distribution between the fossil and recent species. He gave the following list as determined by Mr. Benson:

Gastropoda:

- Melania tuberculata Müll. Not rare.
- Paludina bengalensis Lam. Very common.
- Paludina melanostoma B. Not uncommon.
- Bithynia cerameopoma B. Not rare.
- Bithynia pulchella B. Not rare.
- Bulimus insularis Eh. Not rare.
- Limnaea sp. (? acuminata Desh.) Not common.
- Planorbis coromandelicus Fab. Very rare.
- Planorbis convexiusculus B. Rare.
- Helix asperella Pfr.

Clams:

- Unio marginalis Lam. Common.
- Unio corrugatus Lam. Common.
- Unio caeruleus Lea. Common.
- Corbicula cor. Sow. Very common.

The clams are somewhat larger than the living forms, and so are the two species of *Paludina*. As regards distribution, Theobald states that the land gastropod *Bulimus* is now extremely common throughout central India and the Punjab "and ranges even to Burma and the Red Sea." We take this to indicate that the climate is at present somewhat drier than it was during the middle Pleistocene. Generally there is a greater number of species in the recent fauna as compared with the Pleistocene, and it is again significant that not less than 17 land forms were collected by Theobald from the recent valley surface as compared with 1 from the Pleistocene river drift.

Before critical consideration is given to the vertebrate remains previously found in these upper gravels, we can with confidence list those fossils which Dr. Teilhard and I collected, as determined by him and Dr. E. H. Colbert, of the American Museum of Natural History.

Elephas namadicus Falc. (jaws and molars).
Equus namadicus Falc. (jaw fragment).
Hexaprotodon namadicus Falc. (jaw fragment).
Bos namadicus Falc. (skull and teeth).
Bubalus palaeindicus (skull).
Sus sp.
Trionyx sp.
Emys sp.

In the Calcutta Museum there are preserved earlier collections from which we can add to the foregoing list the following as quoted from Pilgrim (1905):

Ursus namadicus F. and C.
Leptobos frazeri Rüt.
Cervus duvancelli Cuv.[1]
Rhinoceros unicornis Lim.
Stegodon insignis F. and C.
Stegodon ganesa F. and C.
Hippopotamus palaeindicus F. and C.
Pangsura tectus Bell "and other Reptilia."

From this it would appear that there are in this otherwise middle Pleistocene fauna two discordant elements—namely, *Leptobos* and *Stegodon*—both of which occur in the Pinjor zone of the Upper Siwalik series. Dr. Teilhard, who critically examined these specimens in Calcutta, reports that the *Leptobos* of Rütimeyer may well be a damaged skull of *Bos*, and as for *Stegodon* it is apparently represented by tusks or fragments which are altogether too imperfect to permit even generic specifications. Therefore, we prefer to rely on the surely identified types, which show clearly an assemblage typical for the middle Pleistocene of Eurasia (see Hopwood, 1935) and younger than the Pinjor fauna of the Siwalik region. On another occasion Pilgrim (1905) referred the Narbada fauna to a zone lying between the Upper Siwalik beds and the ossiferous late Pleistocene cave deposits of Karnool, in Madras Presidency. To this we agree if by Upper Siwalik is meant the Pinjor

[1] Theobald (1860) mentioned five species of deer, yet he listed only one.

beds exclusive of the conglomerate beds containing *Elephas namadicus* and *Bubalus* at Bubhor (Falconer, 1837). No further detail can be gained from present data concerning the fossil fauna of the upper Narbada group than that it appears to be similar to that of the lower group and that both carry middle Pleistocene mammal remains.

The basal gravels and sands of the upper group are generally less cemented and less coarse than those of the lower group, and the thickness is greater, ranging from 15 to 30 feet and apparently increasing upstream from Hoshangabad. At some places the gravels are replaced by brown cross-bedded sands. At the very base, on the plane of disconformity, the sand is often cemented by lime, which adheres also to the bones, as if they had been indurated from below by ground waters ascending under the influence of intermittent desiccation.

Above it lies again a thick clay bed, though less red and poorer in concretions than the older clay and more silty in composition (fig. 182, 3). The thickness increases between Hoshangabad and Narsinghpur from 30 to 70 feet. The color is commonly pink with a yellow-pink tint varying into brownish. Shells were found at this horizon, which on the whole marks a second stage of aggradation and the end of a second cycle of sedimentation.

In both gravels and pink clays occur rolled flakes and cores which are of early paleolithic type and, what is more significant, a predominant number of which fall well within the typologic range of the "late Soan industry" of northwest India (locality 8). The rolled Acheulian hand axes seem to be restricted to the basal gravel of this zone and hence may be redeposited from the lower beds. The large cores of quartzite and trap encountered at this horizon are fresh and so are many of the "Soan" tools. To be sure, these were also collected from the lower group but not in such quantities and never in association with fresh hand axes. Therefore we are inclined to regard the upper group as contemporaneous with the late Soan.

NEW ALLUVIUM AND REGUR CLAY

Above the upper group there is a sharp break in the sequence due to dissection of the Pleistocene beds, amounting locally to as much as 70 feet. The river must have entrenched itself, and its meanders were cut deeply into the soft rocks of the older drift until it achieved gradient and a new cycle of aggradation began. This led to renewed filling, restricted to the main channel, where (as at locality 7) soft cross-bedded sands and gravels are found to rest against the slopes of the older channels. These beds at many places make the lowest terrace and thin out rapidly toward the flanks, where a few feet of gravel usually overlie the clay of the upper group.

To this alluvium we must also assign a brown silty clay which is known as "regur" or "cotton soil." This deposit covers the greater portion of peninsular India and has long been known as a weathering product of warm temperate and subtropical regions developed on argillaceous rocks. Nothing definite is known about its origin, but all observers, especially Oldham (1893*a*, p. 415), assumed that its formation required heavier vegetation than is found nowadays, because of its

high content of colloids derived from trap and other feldspar-bearing rocks. In this region regur is mixed with silt and fine sand and locally exhibits faint structure, which is absent on higher ground. Undoubtedly regur of this type is an alluvial variety of the true cotton soil, which explains its thickness (30 feet) and content of pebble beds. These beds, and more so the underlying gravels, are composed of flint, chalcedony, jasper, and trap, also quartzite and slate, all of which are well rolled. The clay component is undoubtedly derived from fossil soil developed on the adjoining high ground. Some of the silt may be of eolian derivation, for in order to accumulate on a dissected drained land surface this type of regur could have kept its hold only by intermittent precipitation of wind-borne drift. Living concretions and land mollusks are frequently found, and where the color varies to yellowish tints regur of this type is somewhat loessic in character. Beyond this superficial likeness there is no relationship between the Potwar loess and regur, for whereas the former is a silt of essentially pluvial origin the latter is an impure clay derived from weathering on an ill-drained surface.

In the basal gravel and sands and in the lower few feet was found a flake assemblage characterized by the absence of hand axes or large cores and by the dominance of small blades and scrapers. These tools are made of flint or jasper, clearly indicative of a total change both in technique and in choice of material. We believe that they represent a protoneolithic or later industry which may have flourished in relatively recent times.

THE NARBADA SEQUENCE AND ITS POSSIBLE CORRELATION WITH THE EXTRA-PENINSULAR PLEISTOCENE

As far as our data allow us to judge, we can state (1) that the Narbada sequence comprises three stages, each of which is separated from the next by a disconformity; (2) that the vertebrate fauna of the older drift is of middle Pleistocene type; and (3) that these beds contain specimens representing early paleolithic hand-ax and Soan industries. At first sight this stratigraphic pattern resembles that found in the Potwar region of northwest India, where the Boulder conglomerate, Potwar silt, and younger alluvium make for an equally distinct cycle. However, such superficial resemblance may easily lead to errors, for it must be remembered that we can choose between correlating the Narbada stages either with the four "main zones" of the Punjab Pleistocene or with its "substages" as recorded in the terraces. Should we attempt the former correlation we would on paleontologic grounds feel inclined to equate the "Boulder conglomerate zone" of the Upper Siwalik series with the "lower Narbada group," as had been suggested on previous occasions (De Terra and Teilhard, 1936). But the archeologic records argue strongly against such a correlation, because the "lowest group" contains heavily rolled Abbevillian and fresh late Acheulian hand axes, which in the Punjab appear only connected with the stages younger than the Boulder conglomerate (T1–T2). As it is very improbable that these industries appeared in both regions at such different intervals, we are obliged to take the second alternative—namely, to correlate our sequence with the terrace deposits of the Punjab.

This obviously involves a geologic synchronization for which no proper basis can be given at present, in view of the absence of clear terrace records in the Narbada region. But on archeologic grounds it would seem as if the "lower group" represents the true Acheulian and "early Soan" horizon, and the "upper group" contains examples of a fresh "late Soan" industry. We have seen that in the Punjab these two Stone Age tool complexes are roughly synchronous with T1–T2 and T3–T4 respectively. On such a basis we suggest the following correlation:

Narbada	*Punjab*
Cotton soil	T5
Upper group:	
Pink clay	T4
Sand	T3
Lower group:	
Pink clay	T2
Conglomerate and sand	T1

Certain geologic data support such a correlation. In the first place, it should be noted that the exposed 130 feet of Narbada Pleistocene represents only a fraction of the total valley fill, which makes it probable that the Upper Siwalik equivalents underlie the ossiferous Narbada beds. Also the great unconformity at the base of the lower group and its disconformable contact with the upper group have their counterparts in the Punjab (prominent slopes between TD and T1, T2 and T3, fig. 181). Moreover, the aggradational phases of T3 and T4 in the Punjab coincide with wet phases (third and fourth glacial), just as in the Narbada the "pink clays" seem to repeat a more widespread inundation of the valley.

How much of the "cyclic nature" of the Narbada Pleistocene is due to crustal factors and how much to climatic factors is a problem worthy of further studies.[1]

B. CULTURE-BEARING LOCALITIES

VICINITY OF HOSHANGABAD

A few hundred yards upstream from the main bathing ghat of the town of Hoshangabad a hard cemented conglomerate appears on the lower bank, which, during low water, forms a platform 6 to 8 feet high (fig. 184 and pl. XXX, 2). From this Dr. Teilhard and I extracted four Abbevillian hand axes (pl. XXXII, A) and an equal number of flakes with plain high-angled platforms.[2] The flakes are made of quartzite and trap. Loose on the platform surface were found a few unworn nondescript waste flakes that may be derived from the upper group (layers 4, 5, fig. 184), which is undercut by the river during floods. The basal conglomerate is very coarse, the pebbles ranging from 8 to 12 inches in diameter.

[1] This was discussed by me in an article written after the completion of this manuscript. See De Terra, H., The Quaternary terrace systems of southern Asia and the age of man: Geog. Rev., no. 1, 1939.

[2] The Narbada artifacts were briefly described to me by Paterson and Drummond in the form of a list. This information was incorporated in the text in order to insure a clearer presentation of the subject. In view of the rolled condition in which these tools were found, Paterson thought it advisable to refrain from line-drawing illustration. However, it must be put on record that many of the "Soan" artifacts are unworn, and so are some of the Acheulian tools. I give a few samples in plate XXXII by photographic reproduction.

At locality 4 (fig. 185) the contact between basal gravel and bedrock is well exposed. The cemented basal gravel yielded two Abbevillian hand axes and three rough nondescript cores. Three flakes with plain high-angled platforms were found loose on the lower slope of the bank above the basal gravel, from which they were probably washed out. Fresh flakes were collected a few feet higher up, in loose detritus derived from the gravel of the upper group. The lower beds yielded here a jaw fragment of *Hippopotamus* (*Hexaprotodon namadicus*) and single teeth of *Bos*.

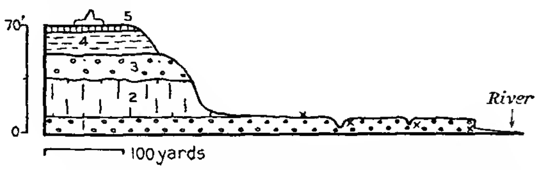


FIGURE 184.—Cross section through left river bank at Hoshangabad. 1, basal gravel; 2, lower clay; 3, upper gravel; 4, upper clay; 5, cotton soil (see pl. XXX, 2). Crosses indicate location of artifacts.

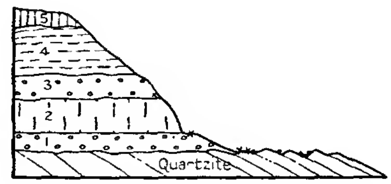


FIGURE 185.—Section on right river bank at locality 4, below railroad bridge. 1–5, same as in figure 184. Crosses indicate location of artifacts.

At locality 6, upstream from the confluence of the Tawa River, fresh specimens of an upper Acheulian industry were encountered in the red clay of the lower group (pl. XXXII, B). We extracted from beds 60 feet below the surface one hand ax, one cleaver, one small core, and eight flakes, of which three had been retouched. In addition, three rolled flakes were found on the lower slope of the bank. This upper Acheulian find in the clay of the lower group is important in view of the fact that no fresh Acheulian tools were encountered in higher beds. We take this to indicate that this horizon marks the upper limit of the Acheulian culture.

Locality 5 (fig. 186) is singularly interesting on account of its situation on an isolated hill of quartzite 2 miles south of Hoshangabad. It is known as the Adam-

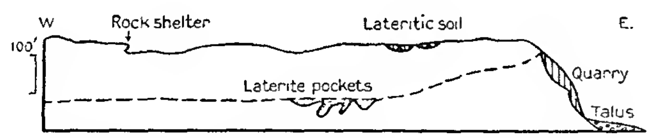


FIGURE 186.—Generalized cross section through Adamgarh Hill (locality 5), near Hoshangabad.

garh quarry, where a rock shelter with cave paintings had been known for some time. So far, no artifacts of great antiquity had been reported from this quarry, but we found three places at which paleolithic tools were uncovered. The quartzite is deeply weathered and has at one time undergone lateritization, as indicated by deep pockets filled with laterite soil, which lie 40 to 50 feet below the hill surface on the eastern slope. These pockets have been exposed by quarrying operations and may be classified in two groups. One kind is filled with primary laterite which is free from implements; the other shows rewashed laterite in which angular

pieces of iron oxide and laterite are mixed with quartz and red sandy silt. In this was found a much rolled core or hand ax of nondescript type, evidently belonging to a tool complex which I discovered on an ancient red soil on the hilltop. At this place, which is 250 yards northeast of the rock shelter, I found in a hollow, 2 feet beneath the surface, an assemblage of three crude Abbevillian-like hand axes, one large flake with edge trimming, one chopper of early Soan type, and two large flakes. In talus near the southern hill slope were found five discoidal cores (one a primitive tortoise core), one flat-bottomed, steep-sided pointed tool, and two pebble choppers, all of which resemble the early Soan types found in the lower Narbada group with early paleolithic hand axes. In fact, this is the age to which we would ascribe the manufacture of the tools, which does not necessarily mean that the rock shelter is as ancient as this industry. The style and technique of the rock drawings argue against such great antiquity, though we believe that the oldest pecked and ocher-painted style of drawings dates back to the end of the Stone Age.

The presence of rewashed laterite with implements in central India was hitherto unknown and is of interest in view of the wealth of early paleolithic hand-ax cultures represented in similar deposits near Madras.[1] It indicates also

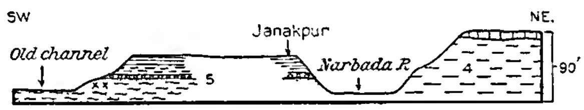


FIGURE 187.—Cross section through a late Narbada filling at Janakpur. 4, 5, same as in figure 184.

that such ancient soils may be widely distributed in the adjoining hills, where fan deposits cover the flanks of the ancient alluvial plain.

It is noteworthy that the refuse or surface soil at the rock shelter yielded great numbers of microlithic tools of chalcedony, which also occur in the regur or cotton soil.

Locality 7 (fig. 187), for instance, yielded such microlithic tools in the basal sand of the regur clay and in association with rewashed specimens of Narbada fossils still bearing the cemented-gravel matrix and sandstone characteristic of the upper gravel. This section reveals the extent of erosion to which the older alluvium was subjected prior to refilling of the Narbada channel and the deposition of regur clay.

VICINITY OF NARSINGHPUR

A very important group of exposures is found north of Narsinghpur, near the village of Devarkachar (fig. 183). Two small tributaries, the Sher and Umar rivers, have dissected the Pleistocene down to the clay of the lower group, which is dark red and full of concretions (pl. XXX, 3). The disconformable contact with the upper gravel and sand is very marked and characterized by prominent bluffs below the village of Umaria (fig. 188, pl. XXX, 1). Here we collected large skulls of *Bos namadicus* and *Bubalus*, teeth of *Hexaprotodon* and *Elephas namadicus*,

[1] See Paterson's report on Madras.

together with several late Soan tools, which are dominant in the upper group. This industry is represented by three small discoidal cores, three small pebble cores (of which one is a steep-ended scraper), one beaked tool, flakes, and four large pebble cores of trap. A few slightly rolled cores and flakes of late Soan type were collected 20 feet above the disconformity. Some 100 yards downstream from the confluence of the rivers on the right bank I extracted from a gravelly sand two fresh late Acheulian cleaverlike hand axes of flint and a large scalloped Soan chopper of trap. Their presence was at first somewhat puzzling considering the older type of industry to which they belong, but their stratigraphic position is such as to suggest their having been derived from a sand lens in the lower group.

This section establishes clearly the continuity of fauna as well as the replacement of the Acheulian culture by a late Soan industry with pebble choppers, beaked tools, and cores.

At locality 9 (fig. 189), on the left bank of the Narbada 1 mile below its confluence with the Umar River, the disconformity between lower and upper groups is very striking because of the assemblage of hard blocks of sandstone upon its

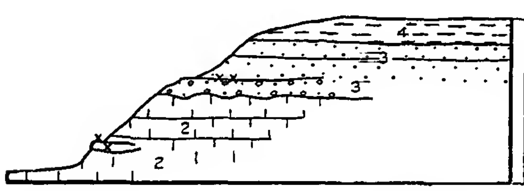


FIGURE 188.—Section at locality 8 through right bank of Umar River. 2–4, same as in figure 184.

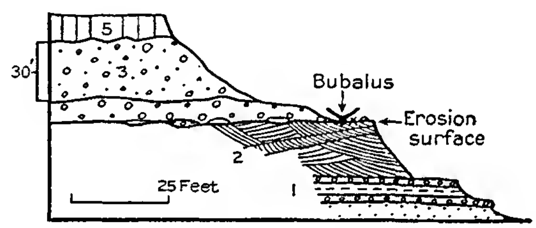


FIGURE 189.—Section at locality 9 through left bank of Narbada River. 1–5, same as in figure 184.

surface. This has caused a resistant ledge, some 40 feet above the stream, on which we found large horn cores of *Bos namadicus*, lamellae of a molar of *Elephas namadicus*, and a few feet distant four heavily rolled Abbevillian hand axes (two on flakes). At the same horizon were collected three less rolled middle Acheulian hand axes and two cleavers. Unworn tools of questionable type include ten large simple Clactonian-like flakes, one core chopper, one pebble core, and one steep-sided pebble tool with step flaking, found in the underlying lower group. Its basal gravel yielded large pebble cores with scalloped edges like the early Soan types and one steep-sided scraper on massive simple flake, all of them greatly worn. These tools are made of trap and quartzite.

The mixture of Abbevillian and early Soan tools with Acheulian hand axes in the upper gravel is easily explained by the fact that this is composed largely of soil detritus from older strata, as indicated by the weathered condition of isolated blocks of fossiliferous sandstone at the level of disconformity. The tools of older type presumably were manufactured on the alluvial flats and redeposited several times by the fluctuating river before embedding took place. If this was shallow the tools may ultimately have weathered out, to be buried once more in the upper gravel together with representatives of later industries. Significant in this place

is the relative abundance of early Soan tools in the lower group, clearly indicating that the tradition of pebble flaking was well established at the time the Abbevillian hand axes were made.

A group of exposures was found several miles downstream, at Barmahn Ghat, where the river is cut mainly into bedrock, trap, and quartzite. (See fig. 183.) The lower group is represented by ocherous cross-bedded sands and gravels 12 feet thick and by 32 feet of tough silty orange clay with lenses of marl. In the stream bed were found three fresh Clactonian-like cores of trap and several flakes that appear to have been washed out from the basal bed, in which we collected two corelike tools of Abbevillian type and a fresh hand ax of quartzite, possibly of lower Acheulian workmanship.

In the upper group, in the indurated sand, was found a large well-flaked nucleus of trap (20 by 15 by 15 inches), and a few inches distant a large flake and a pebble-shaped hammer stone. This is the only place where a clear genetic tool assemblage was found indicative of a workshop on the ancient alluvial flats. The same level, 1½ miles upstream from the village on the right bank, yielded

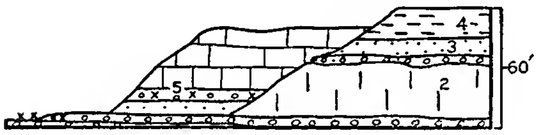


FIGURE 190.—Section at locality 11, near Jhansi Ghat. 2–5, same as in figure 184.

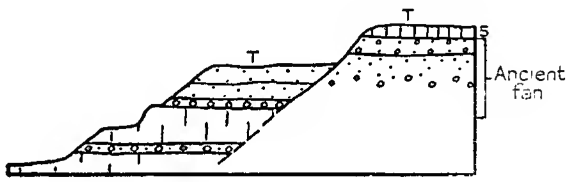


FIGURE 191.—Terrace section at locality 13.

the following rolled tools: two Clactonian-like cores, three large Abbevillian flakes, two large nondescript flakes, one pointed middle Acheulian hand ax, one small cleaver, one side-flake cleaver (Vaal River technique), two corelike tools (? Abbevillian).

Once more the sands near the disconformity show, as at locality 9, a mixture of Abbevillian and Acheulian types, but the absence of Soan tools is noteworthy.

At Jhansi Ghat (fig. 190) the section is complicated by a thick series of brown sand and silt, which overlap the higher terrace from the valley. It has a red clay with indurated gravels at the base. The gravels appear in the river bed only, and from their surface below the cliff we collected two fresh late Acheulian hand axes of brown flint, which had apparently weathered out from the higher bluffs and fallen down amid the heavily rolled pebbles of the basal conglomerate.

At the base of the regur clay brown sands contain many microlithic scrapers, cores, and flakes of chalcedony, which resemble the tools found in the rock shelter near Hoshangabad.

After studying the sections on the banks of the Narbada River it could be expected that the stratigraphic pattern of the ancient alluvium might be found also in the fan formation along the southern hills. Such is actually the case, as illustrated in figure 191, which gives a cross section through the terrace sequence in the outlet of the Shakkar Gorge southwest of Narsinghpur near Hatnapur (fig. 183).

Upon approaching this place the path from Angaon crosses a belt of fans consisting of reddish-brown loam with laterite pebbles interspersed. This is rewashed laterite soil from the hills into which the Shakkar River has cut its bed 140 feet deep. At the outlet near Hatnapur the fan consists of trap boulders somewhat cemented on top and covered by regur clay. The flat surface suggests a terrace cut into the fan, which was subsequently mantled by the weathering products of the volcanic rock. About 18 feet below appears a second terrace covered by brown-pinkish silt interspersed with concretions and underlain by 6 feet of cemented sandy gravel. This lies disconformably on red-brownish clay merging at the bottom into a massive bed of marly concretions and underlain by coarse river gravel. This sequence is a repetition of the Narbada Pleistocene and needs no further interpretation. Of interest, however, are the facts that here the groups appear to be younger than the rewashed laterite fan stage and that the second terrace is aggradational and built of the sandy silt of the upper group. This association of a lower terrace with the upper group is significant in view of the suggested correlation with T3–T4 of the Punjab. Here also pebble cores of early Soan type were extracted from the lower red clay, but tools of late Soan type are dominant above.

PART IV. STRATIGRAPHIC AND TYPOLOGIC SEQUENCE OF THE MADRAS PALEOLITHIC INDUSTRIES

By T. T. PATERSON

The coastal plain of Madras is characterized by the widespread occurrence of a covering of detrital laterite, derived by subaerial processes from the higher laterite-forming plateaus of the hinterland. That these processes were subaerial is shown by the variation in lithologic facies of the laterite, with sand and boulders, and grading seaward. The underlying gneissic surface is an old marine platform of pre-Pleistocene age, which rises inland to 250 feet against the Alicoor Hills, where the thoroughly dissected remains of marine terraces at 500 and 750 feet indicate a still greater submergence in an earlier period. The laterite is cut by several rivers, and four terrace surfaces can be recognized, well exposed on the Cortallaiyar River. Figure 192 is a composite section illustrating the sequence of deposits around the Red Hills close to Madras itself.

On the basal gneisses rests a fluviatile deposit, locally a well-developed boulder conglomerate, lensing laterally into coarse grits and sands. There is a smooth

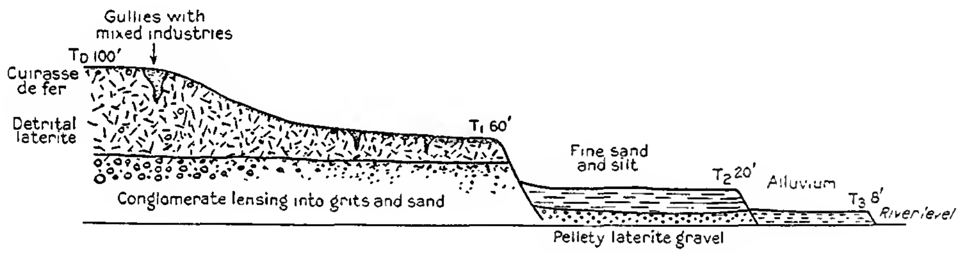


FIGURE 192.—Terrace sequence near Madras.

passage upward into the overlying detrital laterite, in that the pebbles of laterite become more common and the boulders (derived from inland Archean rocks and the Jurassic Cuddapah series) become less numerous. Even at the top of the laterite layers of large pebbles can be found, and sand is common throughout. After deposition of the laterite, forming surface TD, the process of lateritization again proceeded, so that locally the grits or conglomerates have become impregnated with downward-moving solutions carrying a high percentage of lithomarge. On top, the iron has been concentrated, forming a "cuirasse de fer."

The laterite was eroded, producing terrace T1, on which some little deposits of sand and gravel were laid down. This was followed by erosion to T2 where thicker gravels were deposited and then covered by silts and sands. T3 was cut out of these and forms a small terrace of alluvium.

The following is a short description of the industries represented at several horizons. Difficulty was encountered in establishing the age of specimens from the laterite. In the laterite itself are found Acheulian tools, but during the periods of monsoon weather the surface of the laterite becomes soaked and gullied by run-off, with the consequence that late surface tools, even pottery, are washed

down and then covered by rewashed laterite, which subsequently currents together, entombing the modern with the prehistoric. The industries here mentioned are, however, known from stratified deposits.

One of the most important sites in the Madras area is Vadamadurai Tank, a few miles northwest of Madras. The specimens from this site can be divided into three groups. Those of the earliest group, heavily patinated and many of them rolled, are of pre-laterite age and are found in the boulder conglomerate. The second group is of later date and has been stained red through contact with the laterite gravel laid down on top of the conglomerate. The third group, in which the specimens have no lateritic staining and little patination, belongs to a period following the removal of the gravel.

The first group can be further subdivided on grounds of patination and typology into an early and a late series. The former comprises hand axes and cores with a very deep whitish crust. The hand axes are of Abbevillian type, very crude and irregular in outline, with thick pebble butts and much cortex remaining, often on both surfaces of the tool. The flaking denotes a stone technique, producing large, deep, and very irregular flake scars. The cores are large and of a rather nondescript type, mostly oblong or circular, with rough, irregular flaking. The flakes have much cortex remaining on the upper surface, and the primary flaking, where present, is of a very primitive type. Only one or two show any signs of having been retouched. The second series in this first group, which is less heavily patinated, shows a typologic advance, especially in the cores. The hand axes are reminiscent of the earliest Acheulian and show the beginnings of a step-flaking technique, though large free flaking is still commonly used. They are slightly more regular in form, particularly one or two large pointed specimens. The cores are mostly discoidal, with fairly regular alternate flaking. The flakes, none of which show any faceting of the platform, have less cortex and more primary flaking on the upper surface than in the previous stage, but there is still little or no definite retouch.

The second group, comprising lateritized specimens, shows a definite typologic advance. The hand axes resemble the middle Acheulian and have considerably more step flaking, which is flatter and neater than before. They are much more even in outline, pear-shaped and ovate being the most common forms. The cores are mainly of discoidal type, similar to those in the preceding stage, but with more regular flaking. Most of the flakes have primary flaking covering the upper surface, but few, if any, show any definite signs of retouch, and none has a faceted platform.

The specimens in the third group have no laterite staining and but little patination. The hand axes, probably upper Acheulian in date, are of two main types, one comprising ovates with small, fairly flat step flaking, and the other including long and pointed forms with thick pebble butts and large but very neat and regular free flaking. Discoidal cores are found, also a flat type of core, oblong, oval, or square, with a platform prepared at one or both ends, for removing flakes from one surface. None of the flakes, however, show any signs of faceting on the platform. They are mostly fairly thin, with little or no cortex on the upper sur-

face, and a few have been retouched for use, probably, as side scrapers. Only one cleaver has been found at Vadamadurai and it belongs to this third group.

A rather similar series of fairly late Acheulian hand axes, cores, and flakes has been found at Giddalore, in the Kurnool District. It is probably of much the same age (belonging to the gravels of terrace T1) as the third group from Vadamadurai Tank, and includes the same two types of hand axes, identical cores, and numerous flakes, of which only one or two have faceted platforms, though many have been retouched.

At Attrampakkam, near Madras, a very large series of late Acheulian hand axes and cleavers has been collected, several of them being in place in the basal laterite gravel of T2. A few rolled specimens of earlier date, corresponding typologically to the first two groups from Vadamadurai Tank, have been found, but the very great majority are unrolled and are probably of about the same age as the third Vadamadurai group. There are very numerous cleavers, most of which are made on flakes, with the flake surface left untouched or only partially flaked. The Vaal River variant, very common in South Africa, which shows a parallelogrammic cross section, occurs frequently.* In shape many of the cleavers are rectangular, with the butt end straight or convex; in other specimens the sides converge slightly, and some are triangular in outline, the butt end being pointed. The working end is usually straight and at right angles to the axes of the implement. In several specimens, however, the edge is oblique, and in a very few it is either concave or convex. Most of the hand axes are made on flakes, though usually the flake surface is partly or almost wholly trimmed. As in the cleavers, the flaking is for the most part step technique, small, flat, and neat, with small step retouch at the edge. The most common forms are pear-shaped and tongue-shaped, the latter having fairly straight and slightly convergent rather than convex sides. They vary in size from 8 by 6 down to 2 by 2 inches, small and large types being found in fairly equal numbers. There are some S-twist examples.

Alongside the cleavers and hand axes occurs a series of cores and flakes. The cores are mostly of discoidal type, with more or less regular alternate flaking. Several of these have been retouched along the edge, having evidently been adopted as implements. Some of the cores, also with alternate flaking, are more oval in shape, roughly resembling crude, unfinished hand axes. Many of the flakes show faceted platforms, and all have primary flaking covering the upper surface. Some have been neatly retouched to form steep, notched, or ordinary side scrapers.

In addition to the large series of implements from the gravel, all of which are slightly patinated, there is a small group of cores and flakes which are entirely fresh and unpatinated. A few of these have been found in place in the overlying silt; the others on the surface. The cores are mostly large flakes, thick and tabular, worked all around the periphery from the flake surface. Many of the flake tools are very neatly retouched, but few have faceted platforms. At another site a small group of fairly fresh and unstained specimens was found at the base of the silts of T2. It includes two neatly made hand axes, both flat and discoidal cores, and a few flakes.

At various sites in the Red Hills, a few miles northwest of Madras, small collections of surface finds have been made, all heavily lateritized. There is no possible method of dating these, except by typology, because, occurring on the surface of the laterite, they may be of any age since the period of the deposition of the laterite. Typology, however, does not help much in determining the age of the culture to which they should be assigned. Hand axes, cores, and flakes are found. The axes are of two types, some rather crude and ill flaked, others small and neat, with flat, regular step flaking. The cores are mainly of the discoidal type, though a few nondescript pieces with irregular flaking occur. The flakes, very rarely with faceted platforms, are often poor, showing no great skill in manufacture. Others are much finer, with fairly regular primary flaking, and several have neat step retouch, forming steep and ordinary side scrapers. There are two or three small end scrapers on short, broad flakes. On typologic grounds this series may be very late Acheulian, though it is possible that the small group of finely retouched flakes is of later age.

PART V. THE LATE STONE AGE SITES AT SUKKUR AND ROHRI, ON THE LOWER INDUS IN UPPER SIND

A. GENERAL FEATURES AND LOCATION

With the discovery of old Stone Age cultures in the Indus Valley of the Himalayan foothills south of Attock, it became important to know whether these industries could be followed toward the delta or at least to the alluvial plains of Sind, from which Evans (1866) had reported "neolithic" tools. In 1867 General Twemlow commented on flint cores found in layers 4 feet beneath the surface in ancient Indus silt, a find which Blanford (1880) investigated at Sukkur with greater care. According to him the flint cores were also found in fissures of the Eocene chalk in a matrix of red clay and gypsum. The other mode of occurrence—namely, in silt—was interpreted by Blanford as a low terrace deposit which owed its origin to a shifting of the Indus channel. He pointed out that historical records exist according to which the river bed was higher than at present. In recent years Mr. E. S. Pinfold has collected from Rohri and Baluchistan a number of artifacts, which he was good enough to show to me. At once it became apparent that these showed a much more developed technique, unequaled by any other implements from India we had seen, and as the material was flint it seemed that at last we might find a region where abundant workshops could be found.

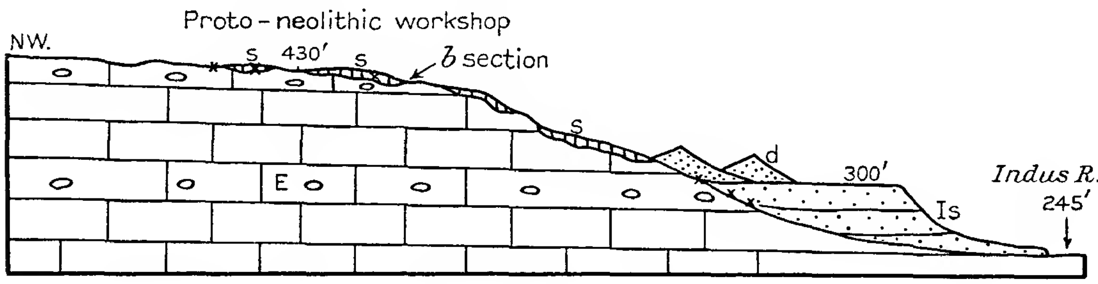
These were actually located during a 2 days' visit to Sukkur by Dr. Teilhard and me, and the same sites were revisited by Mr. J. H. Drummond in the winter of 1937. Our expectations were realized, so far as quantity of worked flint is concerned, but, as will be seen presently, the typologic analysis argues generally against a very great antiquity of these industries.

There are two groups of sites, one on the limestone hill west-northwest of Sukkur and the other on the opposite Indus bank 1½ miles southeast of Rohri. In both localities the workshops lie on the surface of the flint-bearing Eocene limestone, which rises 130 to 160 feet above the stream bed (fig. 193, *a*). The raw material is abundant in the limestone and must have been originally concentrated in an ancient ferruginous soil which covers the hilltops (fig. 193, *b*). This soil ranges from 1 to 3 feet in thickness and is charged with corroded flint nodules and residual limestone breccia, slightly silicified by dissolution of lime through surface water.

The Sukkur site lies 1½ miles west-northwest of the P.W.D. rest house and about 2 miles southwest of the railroad bridge that connects Sukkur with Rohri. The implements (pls. XLV–XLVIII) were collected from the flat hilltop, where native workers could be seen beating the flints to pieces for road gravel to be used in the construction program of the new settlements. If quarrying operations continue it is likely that the site will disappear within a few years. The tools are not rolled, though somewhat patinated (see Paterson's report), and must have been manufactured on the spot, as the composition of the flake leaves shows. At the bottom lie usually large axlike tools which presumably were manufactured

first either as tools (? digging) or waste products ("blanks") in connection with the splitting off of smaller flakes. Cores, waste flakes, and larger scrapers lie on top interspersed with blades and scrapers.

The Rohri sites lie on the dissected hilltops 1 mile south-southeast of Rohri station, beyond the tracks of the Karachi Railroad, and extend farther southeast. They are richer in tools and more numerous and represent factory sites, as the typologic analysis proves (pl. XXX, 4). Gullies and depressions cut into the limestone hills are filled with a fine gray sandy silt with *Planorbis* shells. This deposit lies 60 feet above the river, and wherever a slope site occurs it is found buried under the



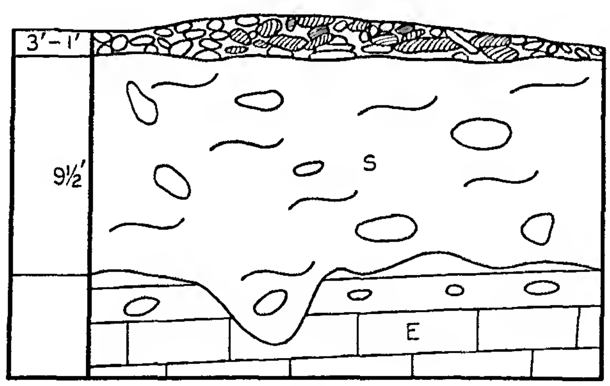


FIGURE 193.—*a*, Section near Sukkur and Rohri. s, soil; d, sand dunes; Is, Indus silt; E, Eocene limestone. *b*, Detailed section at point indicated in *a*.

silt. Above the silt lie migrating dunes. In the depressions of these dunes, some of which are 20 feet high, we collected slender conical cores and very thin long blades reminiscent of the stone industry of Mohenjo Daro. These represent unquestionably the youngest tool type found in this region.

B. GEOLOGIC AGE

The absence of stratified deposits makes it almost impossible to date these cultures. All that can be said is that the hilltop sites are associated with ancient soils of "terra rossa" type, which do not form under present arid conditions. Their origin must date back to a period of greater rainfall, which ultimately may have led

to inundation of the slope relief because of the overlap of lacustrine silt on the hill slopes along the flanks of the old Indus channels. This yellow-gray silt actually buried both the terra rossa soil and some of the factory sites on the valley flanks near Sukkur, and long after lowering of the Indus channel had taken place the great climatic change set in which brought about dune formation and desert varnish. Since it is known that the civilization of the lower Indus Valley flourished at a time of greater rainfall, it might seem as if the formation of red soils on the limestone hills fell into the same climatic phase. However, this can hardly be the case because of the much higher level which the Indus must have occupied when the silt began to bury the slope sites. A higher Indus level at Sukkur necessitated also a higher flood plain at Mohenjo Daro, yet its ruins were found at a level 20 feet below the present valley flat. In other words, there appears to have been still a considerable geologic interval between the formation of the ancient silt and the construction of Mohenjo Daro, during which the river deepened its channel. Hence from a geologic angle we are inclined to give these Stone Age sites a somewhat greater age than their typologic character would admit, which of course may not have exceeded a couple of thousand years.

In view of the uncertain origin of the lower Indus Valley civilization it seems that the presence of such protoneolithic settlements on higher level might lead to a new approach to Indian archeology, which so far has been inclined to stress the foreign derivation of Indian civilization. The Stone Age sites of Sukkur and Rohri may well represent an indigenous culture from which a more or less continuous evolution may have led to the first Indian urban civilization. Its history will be found to have been dictated as much by climate as by the changes of river level, as was the case with the predynastic cultures of lower Egypt.

C. THE INDUSTRIES OF SUKKUR AND ROHRI

By T. T. Paterson

Though the districts of Rohri and Sukkur are genetically connected, geologically and typologically, yet distinct variations in individual industries necessitate separate treatment.

SUKKUR

The specimens from Sukkur were found, as indicated above, mostly on or else very close to the surface, in about two feet of soil with no apparent stratigraphic sequence, except for the tendency in some few places for the heavier implements, hand axes and big cores, to be concentrated near the base. Such a concentration may be due to differential reassortment by wind action. However, the implements can be placed, on grounds of patination, in three groups, which merge into each other. It has been found that these groups represent distinct industries, and it is therefore felt that the initial subdivision on the criterion of patination is justifiable. The same material, a variety of flint, is used throughout.

Group A: Patination dark brown, smoothly polished with a high luster—desert patina.

Blades and flakes occur, the blades greatly in the majority. There are equal numbers of broad and narrow blades, but they are all somewhat crude and thick, with large, bladelike primary flake scars on the upper surface; a few are retouched down one or both sides, and many others chipped through utilization (pl. XLV, 1, 4, 5, 7). A large number, possibly utilized as knives, have a natural "back" of cortex (pl. XLV, 1). The flakes are mostly oval or rectangular in shape (pl. XLV, 2, 3), but a few are triangular, one or two having been retouched to form points. On the upper surface these flakes have primary working in the form of lengthwise blade or flake scars. Only one flake with a definitely faceted platform has been found. Very few cores with the patination of this early group were discovered. All are flat and tabular, flakes or blades being struck off on one surface and from one end only (pl. XLV, 6).

Group B: Patination brown; dull surface with no polish and often with patchy black staining.

In many respects this group is very similar to group A, the chief difference being the presence of some concavo-convex flakes (pl. XLVI, 1), and the appearance of a new technique of primary flaking (resembling the Levalloisian), in which the flake scars are convergent, the core having been prepared by blows struck from all sides (pl. XLVI, 5). Besides these, however, there are many other flakes similar to those found in group A, with lengthwise rather than convergent primary flaking (pl. XLVI, 2, 3, 7). There is a slight increase in the proportion of flakes to blades, and the blades are on the whole rather less thick and crude (pl. XLVI, 4, 6). No flakes with faceted striking platforms were found. Cores similar to those found in group A occur; many of them, however, are flaked on more than one surface and from two or more directions (pl. XLVI, 8). Cores of another type occur very commonly both in this group and group C, described below.

Group C: Fresh and unpatinated. Flakes greatly outnumber blades, which, besides being few, are very small. Many of the flakes are of concavo-convex type (pl. XLVII, 2, 3), but the remainder are mostly flat and thin, usually with convergent flake scars covering the upper surface (pl. XLVII, 7). Thus two different techniques of primary flaking are to be found—one in which the flakes are struck from one direction only, producing concavo-convex flakes, as well as ordinary flakes with lengthwise primary flaking; the other more Levalloisian-like, in which the core is prepared, before the removal of the required flake, by blows struck from all sides. Few of the flakes are retouched, but many show signs of utilization, and all have plain, unfaceted striking platforms. A few "plane" scrapers, with steep trimming, occur (pl. XLVII, 4). Cores of the same type as in group B are found (pl. XLVII, 1, 5), also a very few conical cores, mostly small, with numerous long, narrow, shallow flake scars running from the base to the pointed apex (pl. XLVII, 6). These are closely similar in type and fresh condition to specimens of the earliest Mohenjo Daro culture.

In addition to the flakes and blades there occurs at Sukkur an interesting series of axlike implements and cores. The number of these, however, in comparison with the enormous quantity of flakes and blades, is almost negligible, and they appear to be restricted to a few small areas. None are found with the patination

of the earliest group, the great majority fall into group B, and a few are more or less unpatinated. All stages can be found between a crude, irregular core roughly of hand-ax shape and a perfect coup-de-poing, entirely symmetrical and well flaked (pl. XLVIII, 1–4). Some of the best specimens among the latter type are comparatively fresh and unpatinated. That they have no connection whatever with the Acheulian hand ax is shown, first by the age of the specimens, which in the later ones, according to their patination, at least cannot be earlier than the earliest Mohenjo Daro, and second by the technique, which is different from that used in the Acheulian. A prominent feature is the frequent removal of a flake or blade from one or both ends of the implement (pl. XLVIII, 2), precluding the possibility of a pointed tool, unless there is subsequent retouch. Practically every specimen, whether it is a true ax or merely a core, has relatively broad and slightly convex ends. A further difference is that the flaking is of a type that results in large, deep, and somewhat irregular flake scars, and there is comparatively rare retouch, though on some there is a varying amount of smaller step flaking. This suggests that these axlike forms are cores (pl. XLVIII, 1, 2), though some of the more adaptable specimens were further flaked and retouched to form implements that could be put to various uses (pl. XLVIII, 3, 4).

ROHRI

The limestone plateau on the left bank of the Indus at Rohri has been dissected by intensive erosion, leaving a large number of flat-topped hillocks of all sizes from less than 50 yards to more than a mile in length. Upon the tops of these hills lie quantities of flint flakes, blades, and cores, in a state of preservation similar, in the great majority of the specimens, to that of group C at Sukkur. Two neighboring hills in particular, 200 yards apart, about 60 yards in length and half as much in width, were of great interest as an indication of the growth of specialization in industry. Upon one of these hills there was a perfect example of a blade factory site, and upon the neighboring hill there was another extensive workshop site, where, however, blades were extremely rare.[1]

On the first hill, Rohri 1, were found over 100 blade cores, mostly conical, flaked usually around half to three-quarters of the periphery from a flat under surface toward a pointed or wedge-shaped apex (pl. XLIX, 1, 3–5). Other cores are flat, flaked on one surface only. With these were found several hundred blades (pl. L, 1–18), many of them chipped or broken, but practically all surprisingly crude and irregular, considering the high degree of skill indicated by the perfection of the cores. It is possible that all the best blades were "exported," but even if they were, it is astonishing that hardly one, and, in particular, no single specimen of the relatively short and narrow type indicated by some of the cores (pl. XLIX, 1, 3) was found anywhere throughout the very extensive sites at Rohri. In addition, there were found many flakes that had obviously been produced in subsequent retrimming of cores already prepared and struck (pl. XLIX, 2).

At the site on the neighboring hill, Rohri 2, blades were found to be very rare. Here the true flakes, struck from prepared cores, as distinct from waste flakes and

[1] This information was furnished by J. H. Drummond, M. A., who visited the sites in the winter of 1937.

chips produced in the preparation of cores, are mostly flat and thin, with large primary flaking, usually convergent, on the upper surface, and with plain striking platforms (pl. LI, 2, 3, 5, 6). There are also a few flakes, more or less of concavo-convex type (pl. LI, 4). One or two flakes were found with a bulb of percussion on both surfaces (pl. LI, 1). Plate LII, 2, illustrates a long, narrow, thick blade, which has been roughly trimmed to form a sort of picklike tool. Except for a few steep scrapers, none of the flakes at this site are retouched, though many appear to have been utilized. There are several varieties of cores, but the most common type is a large, irregular block, with flakes struck off on one, two, three, or even more faces. Many of these show signs of preparation. There are also many discoidal cores, mostly large and rough, and others, either oval or triangular in shape, with neat alternate flaking (pl. LII, 1, 3). One or two of the latter appear to have been retouched for use as implements (pl. LII, 3). At this site there were also found enormous quantities of waste flakes and small chips.

The differences in the industries of these two neighboring sites may be conveniently summarized. At one site blades are found in quantity, with few waste flakes except those produced in retrimming of cores; the cores are finely struck, and there are signs of extensive utilization of the blades. At the other site there are few blades, but large quantities of waste flakes of a kind that might well be produced in the initial preparation of cores; the cores are generally coarse, and the true flakes, as distinct from waste chips, are comparatively rare. The fact that there are at the blade site no waste flakes of the kind produced in core preparation suggests that the cores were made elsewhere, and such a "core manufactory" may well have been on the second site, which, on the evidence of the fresh state of preservation, is of an age with the blade site, and, at the same time, is close at hand.

Plate L shows that blades of very fine character must have been made at the blade site, yet no such blades are present. As already suggested, the best blades were probably made for export, but the problem still remains why no really fine blades have been found either at the workshop itself or in any of the neighboring hilltop sites.

DATING

Stratigraphy gives few clues to the age of these industries of the Rohri and Sukkur area, and the dating must depend largely upon comparative typology. The absence of pottery and metal places as an upper limit the Chalcolithic of the Indus. The combination of so many different techniques belonging to the Stone Age suggests that these industries were very late, and the similarities, both in typology and in state of preservation, of the Rohri implements to the stone tools of Mohenjo Daro are indicative of an age approaching that of the earliest period of the Chalcolithic civilization of the Indus Valley. To judge from the fresh state of preservation, group C from Sukkur is of the same age, but groups A and B, which are patinated, are slightly earlier. The fact that no sharp dividing lines can be drawn between the three groups suggests that there has been continuous occupation of the sites, covering, in all probability, only a relatively short period of time.

LITERATURE REFERENCES

Blanford, W. T., The geology of western Sind: India Geol. Survey Mem., vol. 17, pp. 1–192, 1880.

Burrard, S. G., and H. H. Hayden, A sketch of the geography and geology of the Himalaya Mountains and Tibet, Calcutta, 1932.

Colbert, E. H., Siwalik mammals in the American Museum of Natural History: Am. Philos. Soc. Trans., new ser., vol. 26, 1935.

Cotter, G. de P., The erratics of the Punjab: India Geol. Survey Rec., vol. 61, pp. 327–336, 1929.

——— The geology of the part of the Attock district west of longitude 72° 45′ E.: India Geol. Survey Mem., vol. 55, pt. 2, pp. 63–161, 1933.

Dainelli, G., Studi sul glaciale: Sped. ital. de Filippi Rec. sci., vol. 3, 1922.

——— Il sollevamento dell' Himalaya: Mem. geol. e geog. di G. Dainelli, vol. 4, pp. 205–300, 1935.

Deevey, E. S., Pollen from the interglacial beds of the Panggong Valley and its climatic interpretation: Am. Jour. Sci., 5th ser., vol. 33, pp. 44–56, 1937.

De Terra, H., Physiographic results of a recent survey in Little Tibet: Geog. Rev., vol. 24, pp. 12–41, 1934.

——— Geological studies in the northwest Himalaya between the Kashmir and Indus valleys: Connecticut Acad. Arts and Sci. Mem., vol. 8, art. 1, 1935.

——— Himalayan and Alpine orogenies: 16th Internat. Geol. Cong. Rept., vol. 2, pp. 859–871, 1936.

De Terra, H., and G. E. Hutchinson, Evidence of recent climatic changes shown by Tibetan highland lakes: Geog. Jour., vol. 84, no. 4, 1934.

De Terra, H., and P. Teilhard de Chardin, Observations on the Upper Siwalik formations and later Pleistocene deposits in India: Am. Philos. Soc. Proc., vol. 76, pp: 791–822, 1936.

Drew, F., The Jummoo and Kashmir Territories, London, 1875.

Evans, J., On some flint cores from the Indus, Upper Sind: Geol. Mag., vol. 3, pp. 433–435, 1866.

Falconer, H., and E. Cautley, Fauna antiqua sivalensis, London, 1837.

Finsterwalder, R., Die Formen der Nanga Parbat–Gruppe: Zeitschr. Gesell. Erdkunde, Nr. 9/10, pp. 321–341, 1936.

Francke, A. H., Indian Antiquary, vol. 32, pp. 389–391, 1903; vol. 33, p. 216, 1904.

Garbett, C. C., Attock District: Punjab District Gazetteers 29-A, pt. A, Lahore, 1932.

Godwin-Austen, H. H., On the lacustrine or Karéwah deposits of Kashmere: Geol. Soc. London Quart. Jour., vol. 15, pt. 1, pp. 221–229, 1859.

——— Notes on the Valley of Kashmir: Royal Geog. Soc. Jour., vol. 31, pp. 30–37, 1861.

——— On the glacier phenomena of the valley of the upper Indus: British Assoc. Rept., vol. 32, sections, p. 67, 1862.

——— Geological notes on part of the northwestern Himalayas: Geol. Soc. London Quart. Jour., vol. 20, pp. 383–388, 1864.

——— On the post-Tertiary and more recent deposits of Kashmir and the upper Indus Valley: British Assoc. Rept., vol. 50, p. 589, 1880; Nature, vol. 22, p. 450, 1880.

Grinlinton, J. L., The former glaciation of the east Liddar Valley, Kashmir: India Geol. Survey Mem., vol. 49, pt. 2, pp. 289–388, 1928.

Haug, E., Traité de Géologie, 1911.

Hawkes, Chr. and J., and H. De Terra, Paleolithic human industries in the northwest Punjab and Kashmir and their geological significance: Connecticut Acad. Arts and Sci. Mem., vol. 8, pp. 1–14, 1934.

Hayden, H. H., Notes on certain glaciers in northwest Kashmir: India Geol. Survey Rec., vol. 35, pp. 127–137, 1907.

Hedin, Sven von, Southern Tibet, vol. 5, Stockholm, 1922.

Holland, T. H., A preliminary survey of certain glaciers in the northwest Himalaya—Introduction: India Geol. Survey Rec., vol. 35, 123–126, 1907.

Hopwood, A. T., Fossil elephants and man: Geol. Assoc. Proc., vol. 46, pt. 1, pp. 46–60, 1935.
Hora, S. L., On fossil fish remains from the Karewas of Kashmir: India Geol. Survey Rec., vol. 70, 1937.
Huntington, E., The Vale of Kashmir: Am. Geog. Soc. Bull., vol. 38, pp. 657–682, 1906*a*.
——— Panggong—a glacial lake in the Tibetan plateau: Jour. Geology, vol. 14, pp. 599–617, 1906*b*.
Jones, E. T., Notes on the Kashmir earthquake of 30th May, 1885: India Geol. Survey Rec., vol. 18, p. 153 and p. 221, 1885.
Kashmir earthquake of November 14: Nature, vol. 140, p. 886, November 20, 1937.
La Touche, T. D., Lakes of the Salt Range in the Punjab: India Geol. Survey Rec., vol. 40, pt. 1, 1910.
Lawrence, W. T., The Valley of Kashmir, London, 1895.
Lewis, G. E., A new Siwalik correlation: Am. Jour. Sci., 5th ser., vol. 33, pp. 191–204, 1937.
Lundquist, E., Hochasiatische Binnenseesedimente: Connecticut Acad. Arts and Sci. Mem., vol. 10, art. 12, pp. 193–238, 1936.
Lydekker, R., Notes on the geology of Kashmir, Kishtwar, and Pangi: India Geol. Survey Rec., vol. 11, pp. 30–64, 1878; vol. 12, 1879.
——— The geology of the Kashmir and Chamba Territories and the British district of Khagan: India Geol. Survey Mem., vol. 22, pp. 1–344, 1883.
Mason, K. L., The glaciers of the Karakoram and neighborhood: India Geol. Survey Rec., vol. 63, pp. 214–278, 1930.
——— Himalayan Jour., vol. 5, pp. 98–102, 1933.
Matthew, W. D., Critical observations upon Siwalik mammals: Am. Mus. Nat. History Bull., vol. 56, art. 7, pp. 437–560, 1926.
Medlicott, H. B., Notes upon the sub-Himalayan series in the Jammu Hills: India Geol. Survey Rec., vol. 9, pp. 49–57, 1876.
Middlemiss, C. S., Note on the geology of the Salt Range of the Panjab: India Geol. Survey Rec., vol. 24, pt. 1, pp. 19–42, 1891.
——— Sections in the Pir Panjal range and Sind Valley, Kashmir: India Geol. Survey Rec., vol. 41, pp. 115–144, 1910.
——— Lignitic coal fields in the Karewa formation of the Kashmir Valley: India Geol. Survey Rec., vol. 55, pp. 241–253, 1924.
Neve, A., Notes on some Kashmir glaciers: India Geol. Survey Rec., vol. 40, pp. 342–343, 1910.
Neve, E. F., The Pir Panjal range and Tatticooti, Kashmir: Alpine Jour., vol. 21, pp. 31–33, 1902.
——— Beyond the Pir Panjal, London, 1912.
Noetling, F., Beiträge zur Geologie der Salt Range: Neues Jahrb., Band 14, 1901.
Norin, E., Preliminary notes on the late Quaternary glaciation of the northwest Himalaya: Geog. Annaler, Band 7, Heft 3, 1925.
——— The relief chronology of the Chenab Valley: Geog. Annaler, Band 8, Heft 4, 1926.
Oestreich, K., Die Täler des nordwestlichen Himalaya: Petermanns Mitt., Ergbd. 33, Nr. 155, pp. 1–106, 1906.
Oldham, R. D., Some notes on the geology of the northwest Himalaya: India Geol. Survey Rec., vol. 21, pp. 149–159, 1888.
——— A manual of the geology of India, Calcutta, 1893*a*.
——— The river valleys of the Himalaya: Manchester Geog. Soc. Jour., vol. 9, pp. 112–125, 1893*b*.
——— Notes on the glaciation and history of the Sind Valley, Kashmir: India Geol. Survey Rec., vol. 31, pp. 142–161, 1904.
——— The valleys of the Himalayas: Geog. Jour., vol. 30, pp. 512–516, 1907.
Oliver, D. R. G., Notes recorded in August, 1911, on some of the lakes of Ladakh: India Geol. Survey Rec., vol. 42, pp. 127–132, 1912.
Pascoe, E. H., The petroleum occurrences of the Punjab and the northwest Frontier Province: India Geol. Survey Mem., vol. 40, pt. 3, pp. 337–371, 1920*a*.

Pascoe, E. H., The early history of the Indus, Brahmaputra, and Ganges: Geol. Soc. Jour., vol. 75, pp. 138–157, 1920*b*.

Penck, A., and E. Brückner, Die Alpen in Eiszeitalter, vol. 3, Leipzig, 1909.

Pilgrim, G. E., On the occurrence of *Elephas antiquus* (*namadicus*) in the Godavari alluvium, with remarks on the species, its distribution, and the age of the associated Indian deposits: India Geol. Survey Rec., vol. 32, pp. 199–218, 1905.

——— Preliminary note on a revised classification of the Tertiary fresh-water deposits of India: India Geol. Survey Rec., vol. 40, pt. 3, pp. 185–205, 1910.

——— The correlation of the Siwaliks with mammal horizons of Europe: India Geol. Survey Rec., vol. 43, pt. 4, pp. 264–326, 1913.

——— Suggestions concerning the history of the drainage of northern India: Asiatic Soc. Bengal Jour., new ser., vol. 15, pp. 81–99, 1919.

——— Correlation of ossiferous sections in the upper Cenozoic of India: Am. Mus. Novitates, no. 704, 1934.

Pinfold, E. S., Notes on structure and stratigraphy in the northwest Punjab: India Geol. Survey Rec., vol. 39, pp. 137–160, 1918.

Prashad, B., On a collection of land and fresh-water mollusks from the Karewas of Kashmir: India Geol. Survey Rec., vol. 56, pp. 356–361, 1925.

Purdon, W. H., On the trigonometrical survey and physical configuration of the valley of Kashmir: Royal Geog. Soc. Jour., vol. 31, pp. 14–30, 1861.

Stiffe, A. W., Note on the glaciation of parts of the valleys of the Jhelam and Sind rivers in the Himalaya Mountains of Kashmir: Geol. Soc. London Quart. Jour., vol. 46, pp. 66–67, 1890.

Strachey, R., Remarks upon a flood in the Indus, August 10, 1858: Asiatic Soc. Bengal Jour., vol. 27, pp. 366–367, 1858.

Teilhard de Chardin, P., The Pleistocene of China, stratigraphy and correlations: Contribution to volume "Early Man," Philadelphia, 1937.

Theobald, W., Notes on the geology of the Punjab Salt Range: Asiatic Soc. Bengal Jour., vol. 23, pp. 651–678, 1854.

——— On the Tertiary and Alluvial deposits of the central portion of the Nerbudda Valley: India Geol. Survey Mem., vol. 2, pp. 279–298, 1860.

——— Occurrence of erratics in the Potwar: India Geol. Survey Rec., vol. 10, pp. 140–143, 1877.

——— On some Pleistocene deposits of the northern Punjab and the evidence they afford of an extreme climate during a portion of that period: India Geol. Survey Rec., vol. 13, pt. 4, pp. 221–243, 1880*a*.

——— On the discovery of a celt of paleolithic type in the Punjab: India Geol. Survey Rec., vol. 13, pt. 3, 1880*b*.

——— The Siwalik group of the sub-Himalayan region: India Geol. Survey Rec., vol. 14, pt. 1. pp. 66–125, 1881.

Thompson, Th., Western Himalaya and Tibet, London, 1852.

Tracey, H. A., Ancient glacier action in the Punjab, with special references to Mr. Mattien William's theory: Jour. Sci., 3d ser., vol. 1, pp. 338–340, 1879.

Trinkler, E., Geographische Forschungen im westlichen Zentralasien und Karakorum-Himalaya, Berlin, 1932.

Troll, C., Der Nanga Parbat als Ziel deutscher Forschung: Zeitschr. Gesell. Erdkunde, Nr. 1/2, pp. 1–26, 1938.

Twenhofel, W. H., Treatise on sedimentation, London, 1926.

Van Vleck-Andersson, R., Tertiary stratigraphy and orogeny of the northern Punjab: Geol. Soc. America Bull., vol. 38, 1927.

Vigne, G. T., Travels in Kashmir, Ladak, Iskardo, 2 vols., London, 1842.

Vredenburg, E., Pleistocene movement as indicated by irregularities of gradient of the Narbada and other rivers in the Indian peninsula: India Geol. Survey Rec., vol. 33, pt. 1, 1906.

Wadia, D. N., Geology of India, London, 1926.
——— The geology of Poonch State (Kashmir) and adjacent portions of the Punjab: India Geol. Survey Mem., vol. 51, pp. 185–370, 1928.
——— The syntaxis of the northwest Himalaya; its rocks, tectonics, and orogeny: India Geol. Survey Rec., vol. 65, pp. 189–220, 1932.
——— The Cambrian-Trias sequence of northwestern Kashmir: India Geol. Survey Rec., vol. 68, pp. 121–176, 1934.
Weller, M. J., The Cenozoic history of the northwest Punjab: Jour. Geology, vol. 36, no. 4, 1928.
Wodehouse, R. P., and H. De Terra, The Pleistocene pollen of Kashmir: Connecticut Acad. Arts and Sci. Mem., vol. 9, art. 1, 1935.
Workman, F. B. and W. H., Ice-bound heights of the Mustagh; an account of two seasons of pioneer exploration and high climbing in the Baltistan Himalaya, London, 1908.
——— Peaks and glaciers of Nunkun, London, 1909.
Wynne, A. B., Notes on the Tertiary zone and underlying rocks in the northwest Punjab: India Geol. Survey Rec., vol. 10, pp. 107–132, 1877.
——— On the geology of the Salt Range in the Punjab: India Geol. Survey Mem., vol. 14, 1878.
——— Further notes on the geology of the upper Punjab: India Geol. Survey Rec., vol. 12, pp. 114–133, 1879.
——— Traveled blocks of the Punjab: India Geol. Survey Rec., vol. 14, pp. 153–154, 1881*a*.
——— On the connection between traveled blocks in the upper Punjab and a supposed glacial period in upper India: Geol. Mag., vol. 8, pp. 97–99, 1881*b*.

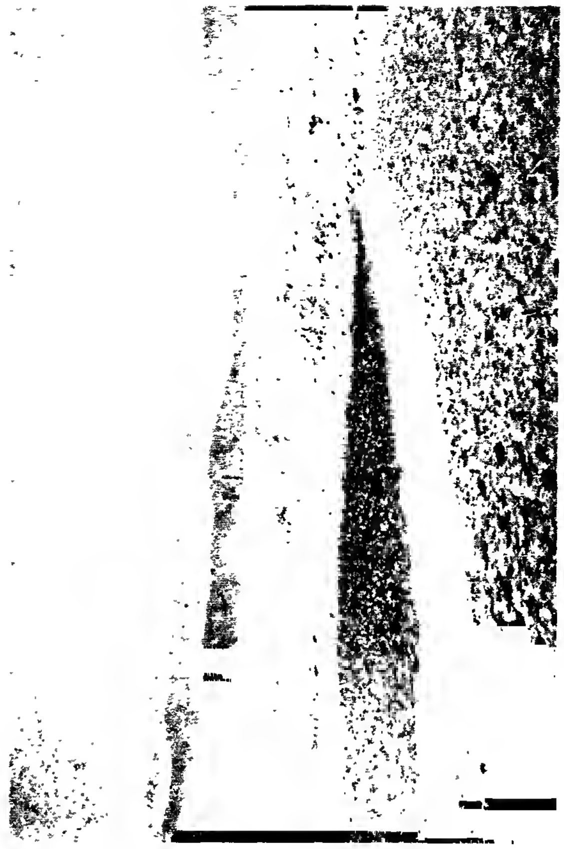
INDEX

C

1. Tawi Valley outlet on border of foothills at Jammu, incised in Upper Siwalik conglomerate.

2. High Pir Panjal as seen from Chinamarg, Tosh Maidan.

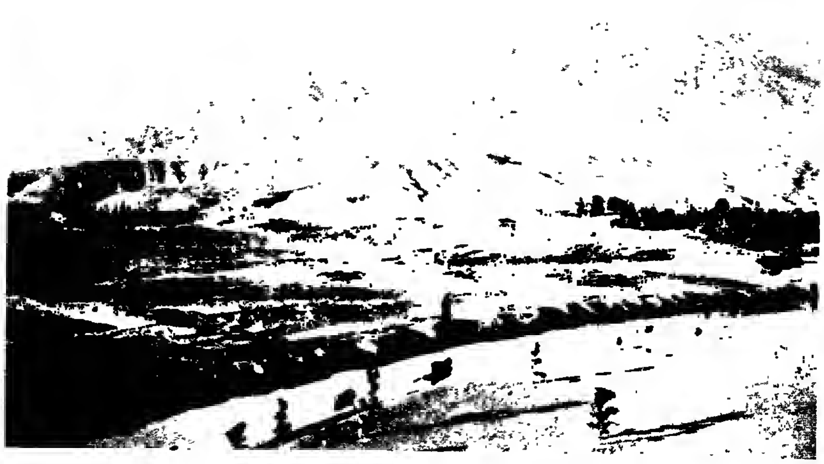
3. Forested Karewa beds near Sedau.



4. Kashmir Valley with rice fields in foreground and snow-covered Pir Panjal in background.

1. View across Kashmir Valley from Takht-i-Suleiman at Srinagar, showing Jhelum flood plain, Karewa Hills, and Pir Panjal.

2. Fault-line scarp on Himalayan slope of Kashmir Basin near Gandarbal.



3. Great Karewa terrace and Jhelum plain near Bijbiara.

1. Sind Valley from Mohand Marg. Main terrace at right covering Mangom moraine.

2. Sind Valley from point above Gandarbal.

1. Contact of Woyil conglomerate and Mangom moraine.

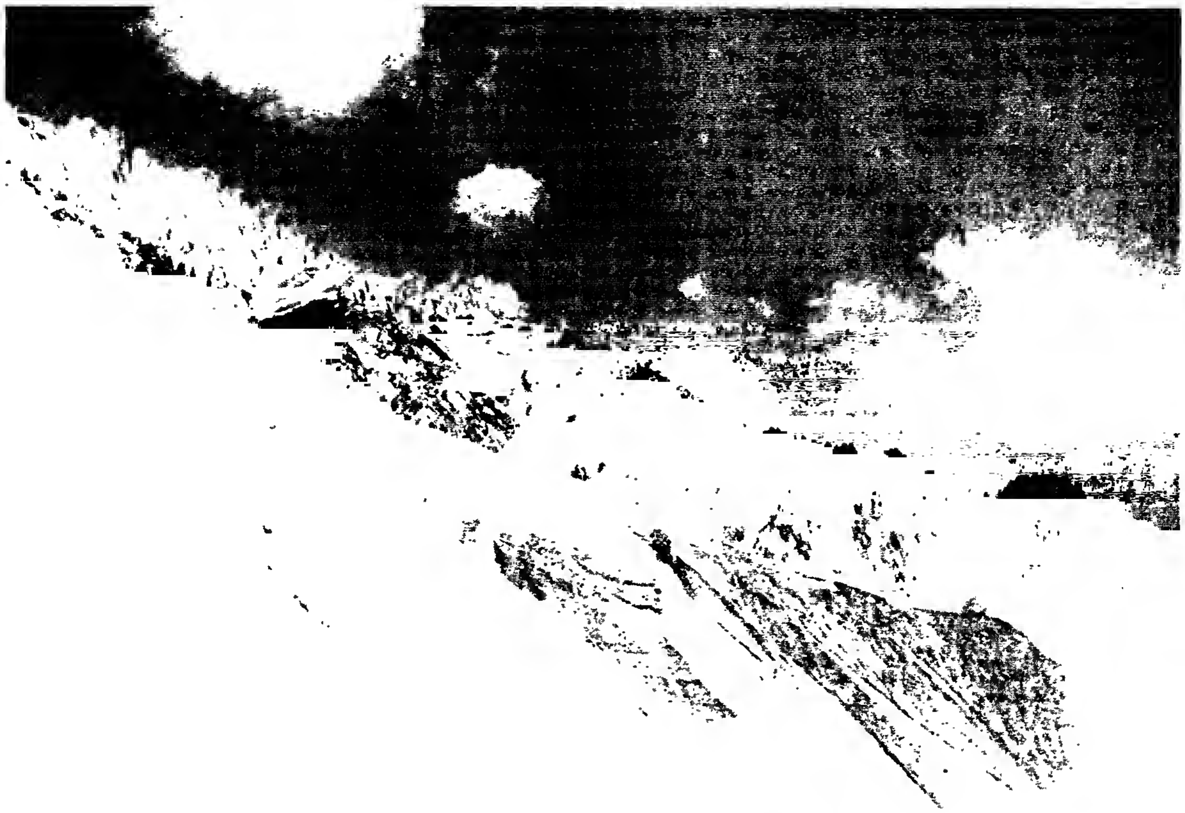
2. Erratics in second glacial clay below Woyil.

1. Solifluxion deposit at the base of the second interglacial deposit at Benahom.

2. Third glacial solifluxion scree at Tserawan. (See fig. 27, B.)

1. Glaciated floor of first glacial age 500 feet above valley floor opposite Sura Pharao. (See fig. 29.)

2. The Sonamarg Basin from the east.



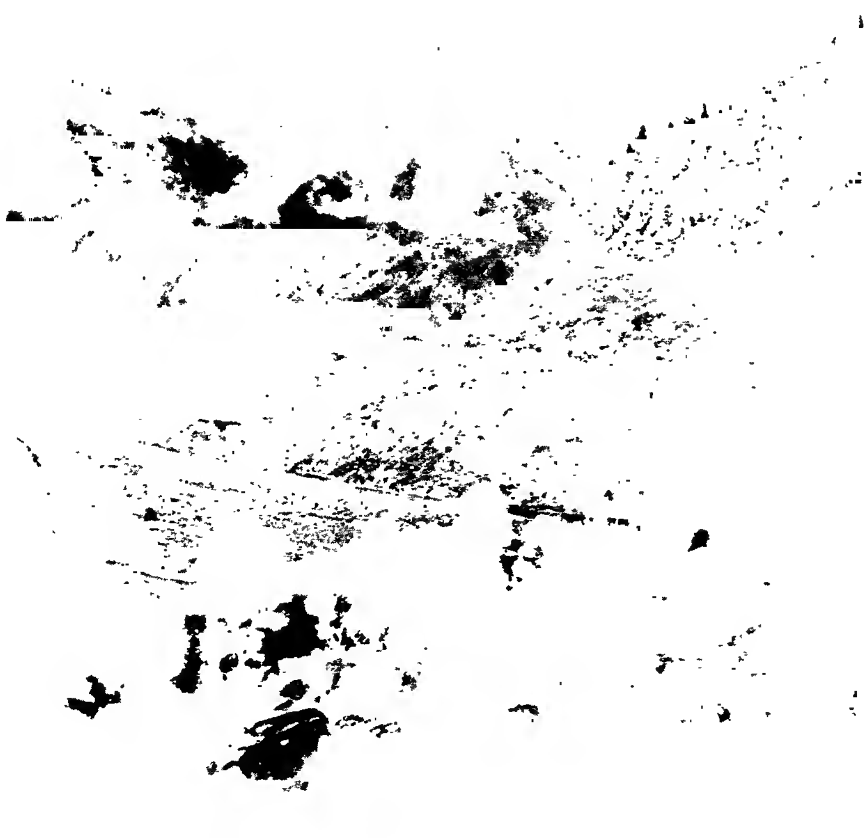
1. Tilted second interglacial cemented tan breccia of the Sonamarg.

2. Almost horizontal cemented third interglacial conglomerate at west end of Sonamarg Basin.

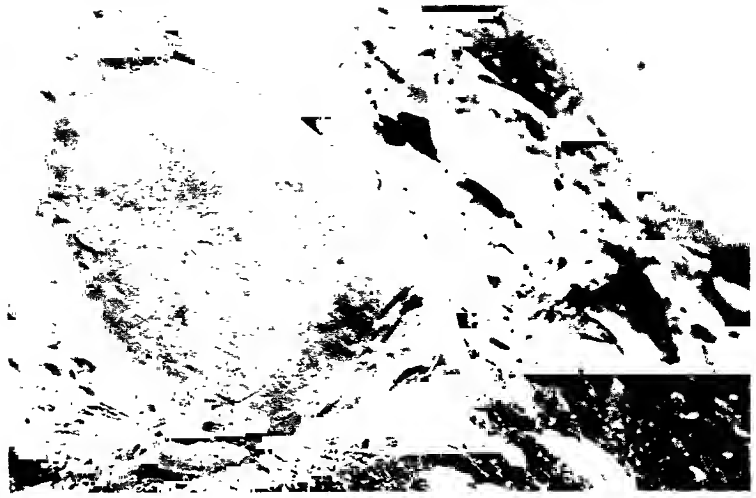
1. View upstream from Sonamarg. See text for explanation.

2. View from Islamabad Hill toward Bawan. Note extensive T_1 and T_2 visible in distance but missing closer to Islamabad.

1. Kanjdori Hill from the west.

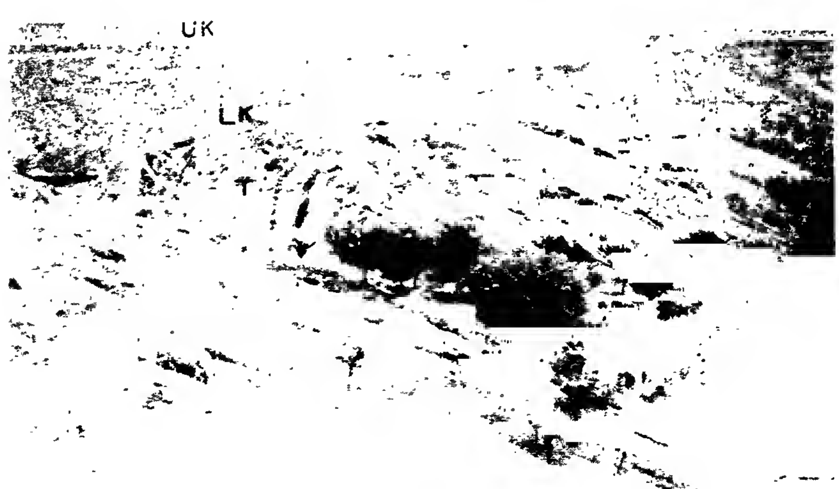


2. Nekabatun Gorge, showing composite slope profile of first and second glaciations. Third moraine banked against second interglacial gorge.

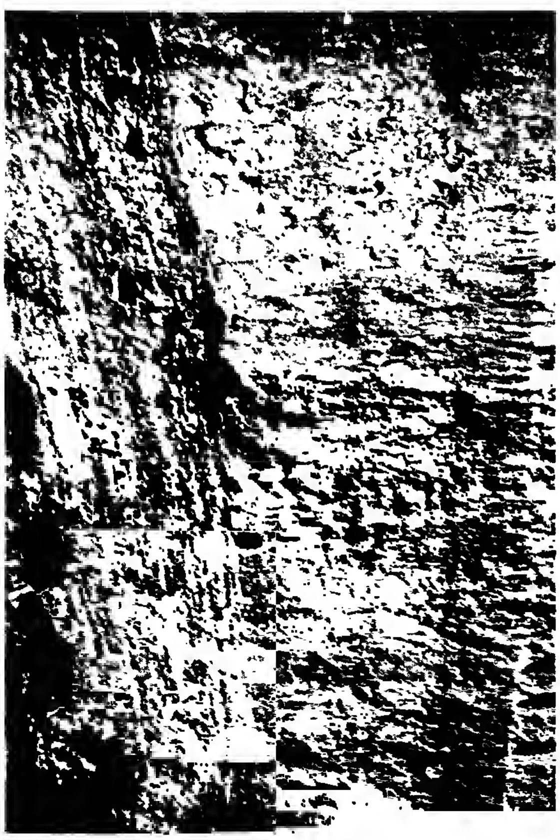


1. Striated boulder in second glacial conglomerate, Piush Gorge.

2. Sombur quarry with elephant bones uncovered in first interglacial clay.



3. Triassic limestone (T) overlain by Lower Karewa shore deposits (LK) and loessic beds of Upper Karewa age (UK) near Sombur.



1. Ancient soil profile in loamy silt covered by younger scree near Gandarbal, Sind Valley.

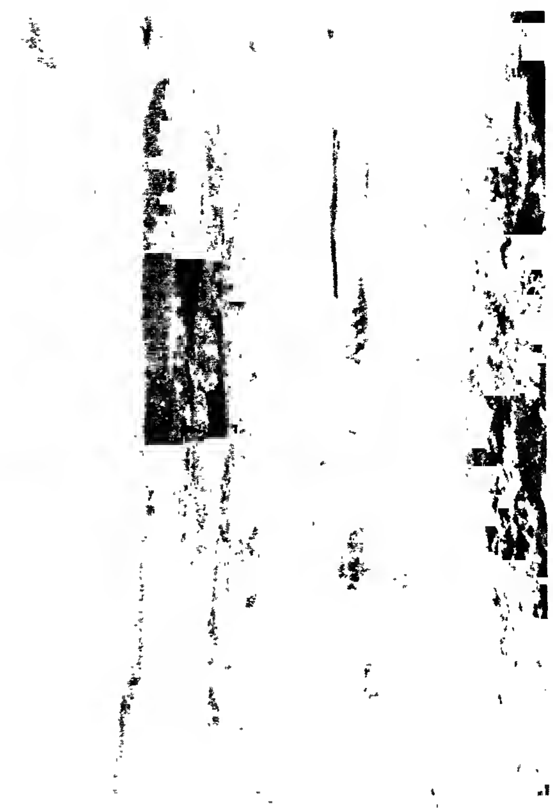
2. Island mountain of trap mantled by Karewa beds near Magam.

3. Takht i Suleman as seen from Gagribal. B, lower bench.

1. Upper portion of Bren spur with raised beaches above fields cut into bedrock. In background, Dal Lake and outlet of Sind Valley.

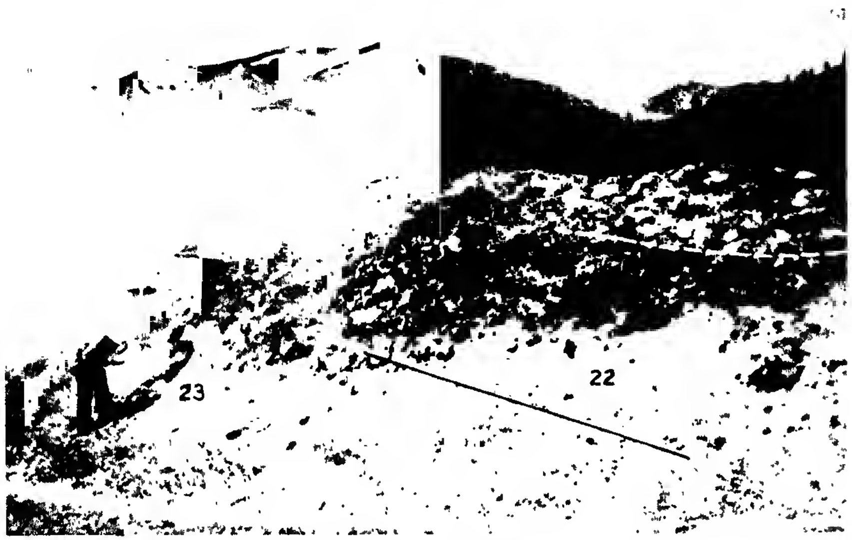
2. Raised beaches above Wuyan.

3. View from point below Nilnag on dissected Karewa beds, with flooded Jhelum plain in background.

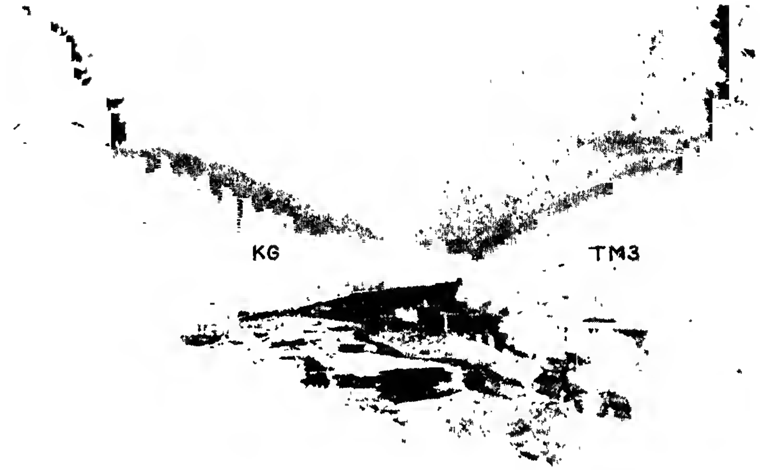


4. Karewa terraces and Pir Panjal slope southeast of Magam.

Panorama view of high Pir Panjal from Chunamarg (13,200 feet). Preglacial mature relief modified by glaciation.



1. First interglacial (Lower Karewa) lake beds with fossil localities (22, 23) in Ningle Valley at 9,800 feet. G2, second glacial outwash.



2. Rimbiara Valley at Hurapur. KG, Karewa gravel terrace; TM3, third terminal moraine banked against second interglacial slope.

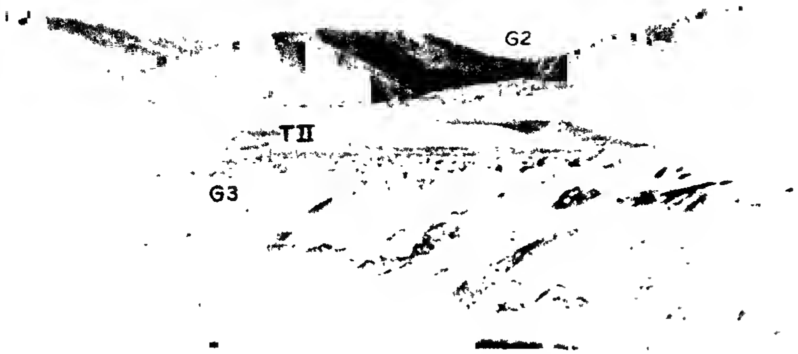
3. Lower Karewa fan (tilted), overlain by third glacial gravel on left bank of Vishav River near Sedau.

1. Lower Karewa beds (zone 4) exposed on 300-foot cliff in Shaliganga Valley.

2. Cliff below Dangarpur at 6,350 feet. Lower Karewa conglomerate (15 feet) underlain by gray shell-bearing clay and overlain by lignite-bearing sand.

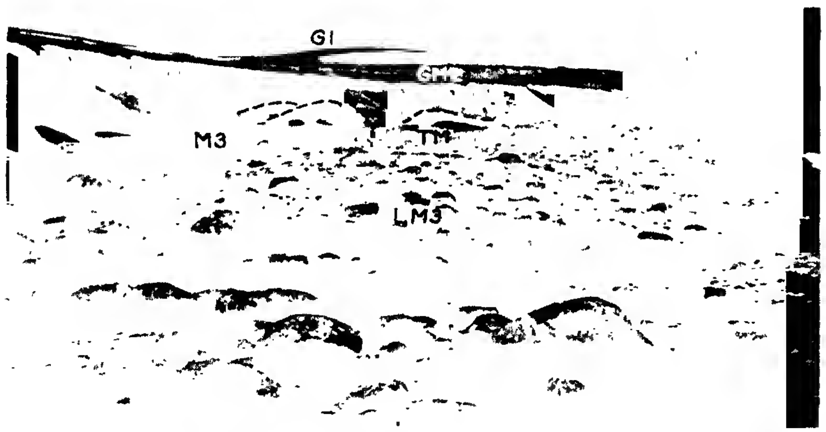
3. Glacier remnants on watershed range, Goraparhri, upper Harseni Valley.

Faulted anticline in Lower Karewa clay overlain by second glacial outwash below Shupyan.



1. Basam Gali Pass (G2), a second glacial trough in watershed range. GM2, second ground moraine; TII, second terrace; G3, third moraine.

2. Glacial slope profiles on border of Tosh Madan. GII, GIII, second and third glacial troughs; T3, third interglacial terrace; G4, fourth glacial deposits.



3. Relations of three glaciations at Chinamarg. *G1, first glaciation*; GM2, *ground* moraine of second glacier; M3, third glaciation; TM, terminal moraine; LM3, lateral moraine of third glacier, at 12,200 feet.

4. Watershed of Tosh Madan toward Kashmir Basin, with third glacial *overflow trough* (G3). G4, *fourth glacial deposits.*

1. Structure soil at 13,800 feet on third moraine of Tosh Maidan. GM2, ground moraine of second glacier

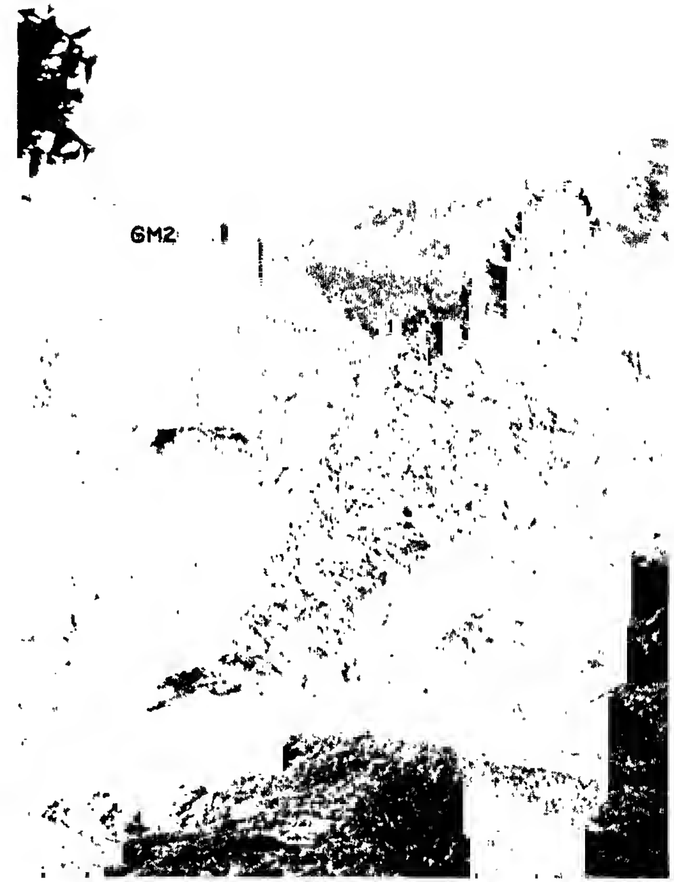
2. Third moraine (TM3) between Hatbar and Drang, at 6,850 feet.

3. Outlet of Sokhnagh Valley at Zugu, with dissected and terraced Karewa Hills. Fault escarpment of Tosh Maidan in background. TM3, terminal moraine of third glacier; TIII, TIV, terraces.

4. Tilted Lower Karewa beds (LK) overlain by third glacial gravel (G3), on which TIII developed, above Zugu. TI, TIV, terraces.

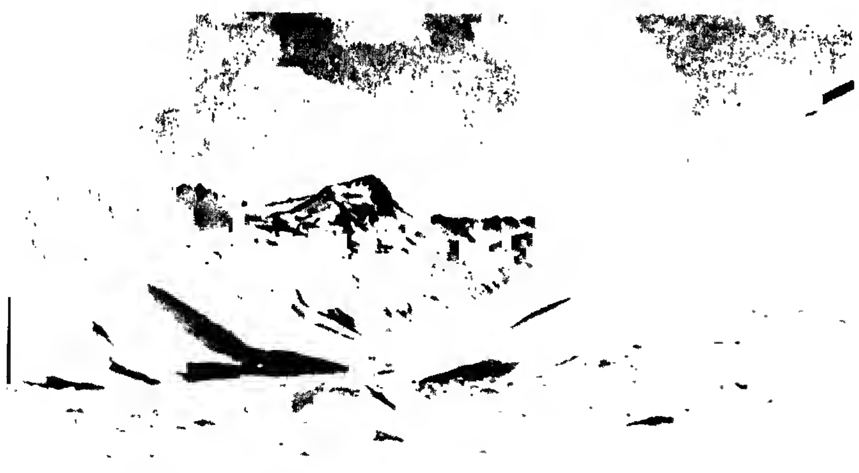
1. Harsent Nar (HV) from point below Tsurugul Pass. G2, G3, G4, deposits of second, third, and fourth glaciers; T, terrace, GM2, ground moraine of second glacier

2. Preglacial relief remnant (PG) and second glacial trough (G2) opposite Shahkut, upper Vishav Valley.



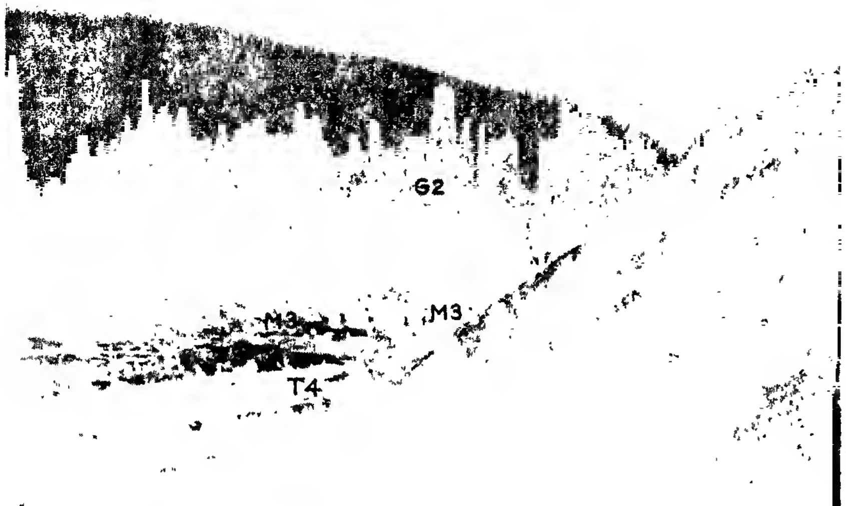
3. Harsent Valley above Sedau, displaying second and third troughs (G2, G3) and ground-moraine filling (GM2).

1. Terraced outlet of Vishav River near Sedau. TI, TII, etc., terraces; G3, third glacial deposits; LK, Lower Karewa beds.



2. Harsent Nar at 11,800 feet, with glacier remnants on watershed.

3. Tilted Lower Karewa beds (LK) overlain by third glacial gravel (*GIII*) *on left* bank of Vishav River below Sedauthur. T2, T3, T4, terraces.

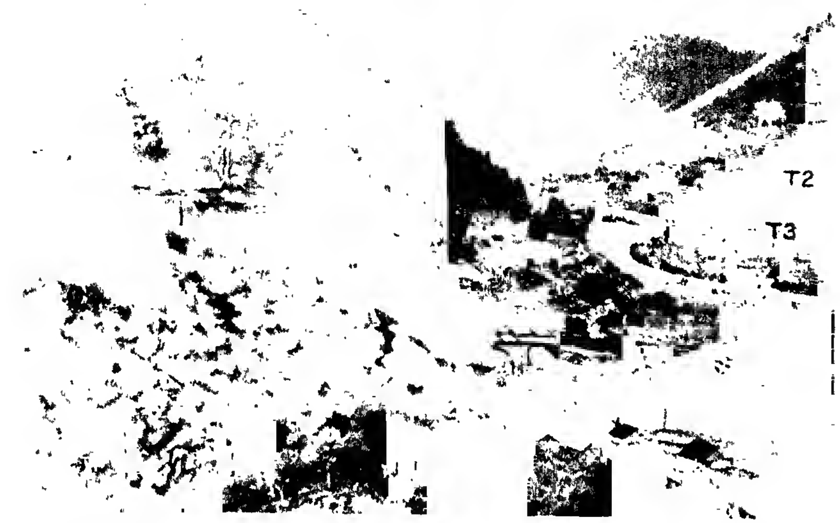


1. Ferozepur Valley at Drang, with snowy Pir Panjal in background. M3, terminal moraine of third glacier; G2, second glacial trough; T3, T4, terraces.

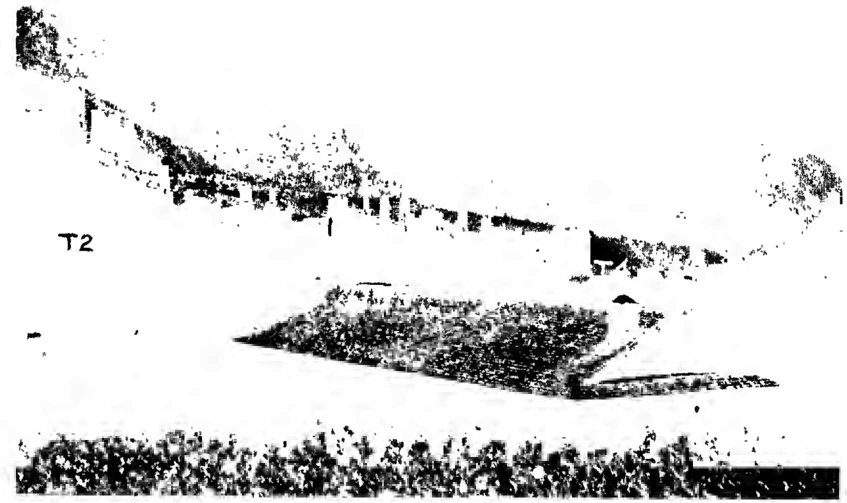
2. Karewa (second glacial) gravel on road above Tangmarg, Ferozepur Valley.

3. Ferozepur Valley at Tangmarg. KG, Karewa gravel; T3, terrace.

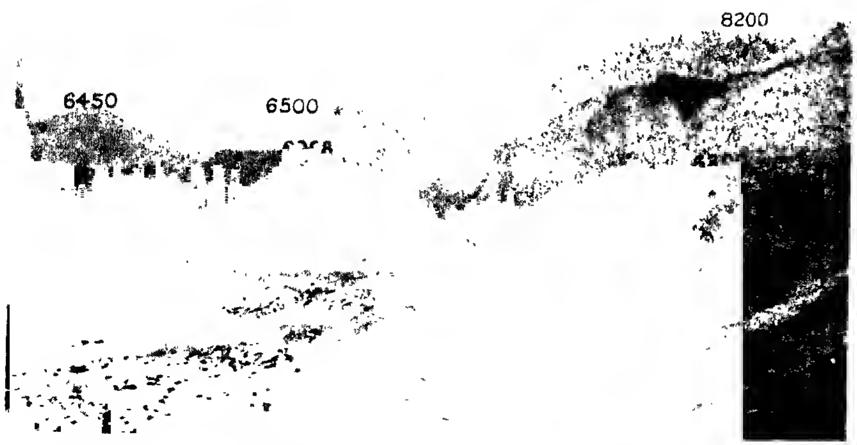
4. Third moraine at 6,320 feet, near Dangarpur.



1. Ground moraine of second Jhelum glacier (G2) near Naushera and Jhelum terraces (T2, T3, T4).



2. Giant fan opposite Naushera and Jhelum terraces (T1, T2, T4).



3. Jhelum Gorge at Baramula (5,190 feet), with ancient divide in background (6,450–8,200 feet).

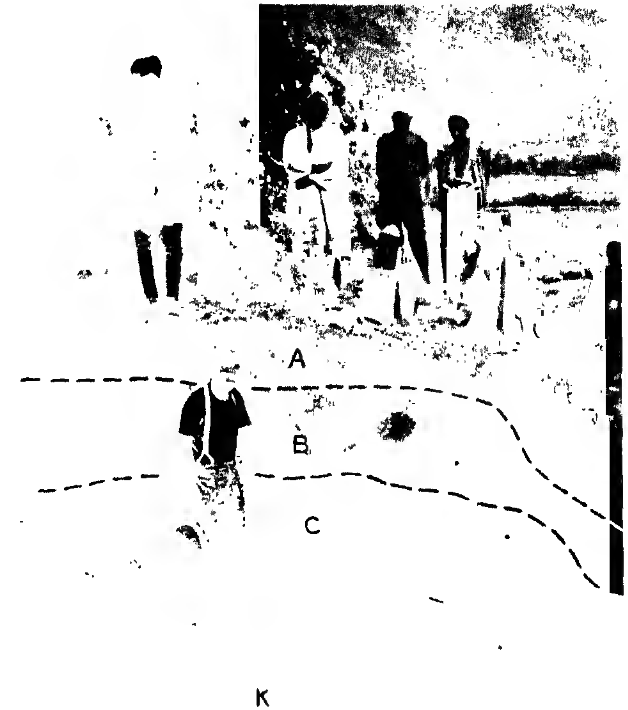
4. Upper Siwalik fan tilted and dissected by Tawi River near Jammu. (See fig. 11[illegible].)

1. Tilted and terraced Boulder conglomerate fan in Chenab Valley above Akhnur. T1, T2, etc., terraces.

2. Northeast slope of Udhampur Basin. On right, older Upper Siwalik beds (U. S.) overlain by second glacial boulder fan. In background, fault escarpment. (See fig. 106.)

3. Terraces (T1–T5) in Udhampur Basin in Barum Nullah.

1. Trial excavation at the megalithic site of Burzahom.



2. Trial trench at Burzahom, showing hearth level (K) in postglacial loess (C). B, "Chalcolithic" (?) layer; A, Buddhist era (about A.D. 300).

3. Stone tools and bone awl from layer C and surface (S) at Burzahom.

4. Various types of potsherds from Burzahom. C, mat design and incised ceramics on hard gray hand-made pottery; B, from layer B.

1. Potwar peneplain over Middle Siwalik beds west of Chaumtra, with Khair-i-Murat ridge in background.

2. Soan Valley near Chakri, with Khair-i-Murat in background.

3. Loess landscape in Potwar silt.

4. Fault escarpment of Khair-i-Murat with dissected pediments.

1. Soan workshop above Adial, with redeposited (fourth glacial?) loam in foreground. (See fig. 167.)

2. Boulder conglomerate with erratics (B.C.) on tilted Upper Siwalik beds (U.S.) with bone bed (+) on Haro River near Campbellpore.

3. Erratic boulder on T2 near Campbellpore. Pecked petroglyphs on surface.

4. Boulder conglomerate tilted to 85° capped by tufa near Golra, Punjab.

1. "Khuddera" or loess canyons near Sohawa, eastern Potwar.

2. Terraced outlet of Kurang Valley on border of Murree Hills near Barakao. B.C., Boulder conglomerate; T_2, T_3, T_4, terraces

3. Potwar peneplain over Pliocene Siwalik beds mantled by Potwar silt and dissected, near Malakpur.

4. Lei River meandering through Lower Siwalik beds. Terraces (T_3, T_4) and Potwar peneplain.

1. Right slope of Soan Valley above Chauntra. Terraces 2 and 3 on Boulder conglomerate.

2. Right slope of Soan Valley near Bandhar. Terraced Boulder conglomerate ridge (T1) in left background. T, terrace.

3. Pinjor silt overlain by Boulder conglomerate (B.C.) and Potwar loessic silt (Ps), unconformable on folded Pliocene Dhok Pathan beds (D.P.) in Soan Valley.

4. Soan workshop level (S) between Potwar loess and Soan gravel.

1. Human skull of neolithic(?) age in postglacial loessic soil southeast of Rawalpindi.

2. Potwar loess (Ps) over Boulder conglomerate with Soan workshop (W) on terrace ledge above Chauntra.

3. Old (second glacial?) conglomerate over Dhok Pathan beds and upper edge of T_3 at hand axe site near Chauntra.

4. Late Soan workshop (crosses) at base of Potwar loess at Pir Abdul, near Gila Kalan, Soan.

1. View into Narbada Valley north of Narsinghpur, with Vindhya Range in background.

2. Locality 3 at Hoshangabad. (See fig. 184.)

3. Upper Narbada group in Sher Nullah, near Narsinghpur.

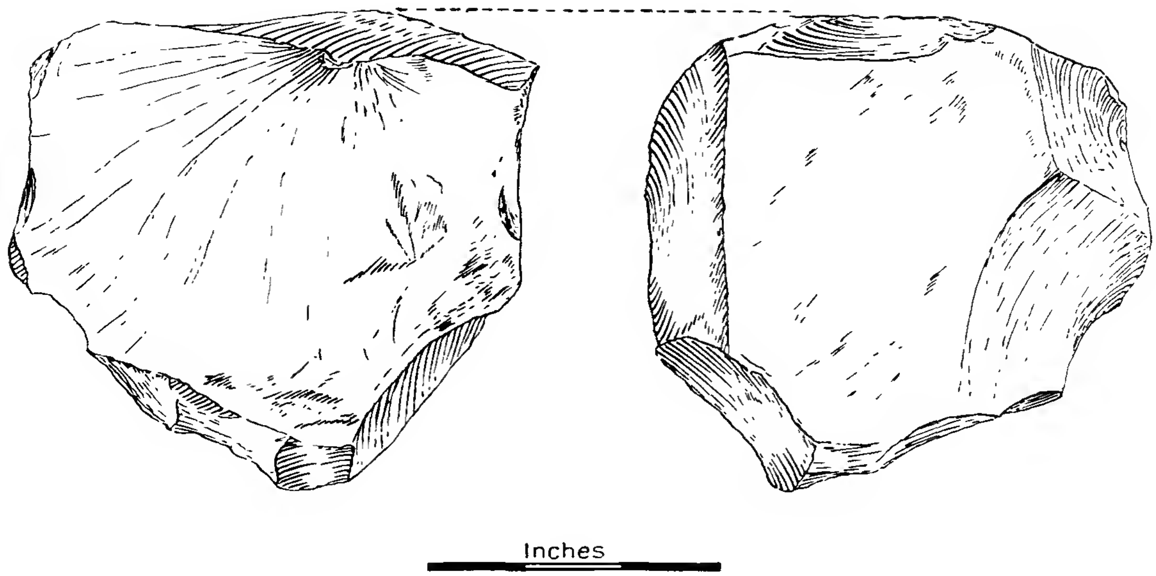
4. Factory site near Rohri, upper Sind.

Paleolithic implements from Soan Valley. A, flakes from Boulder conglomerate; B, Abbevillian hand axes from Chauntra, C, early and late Acheulian tools from Chauntra and T1, D, cores of late Soan type

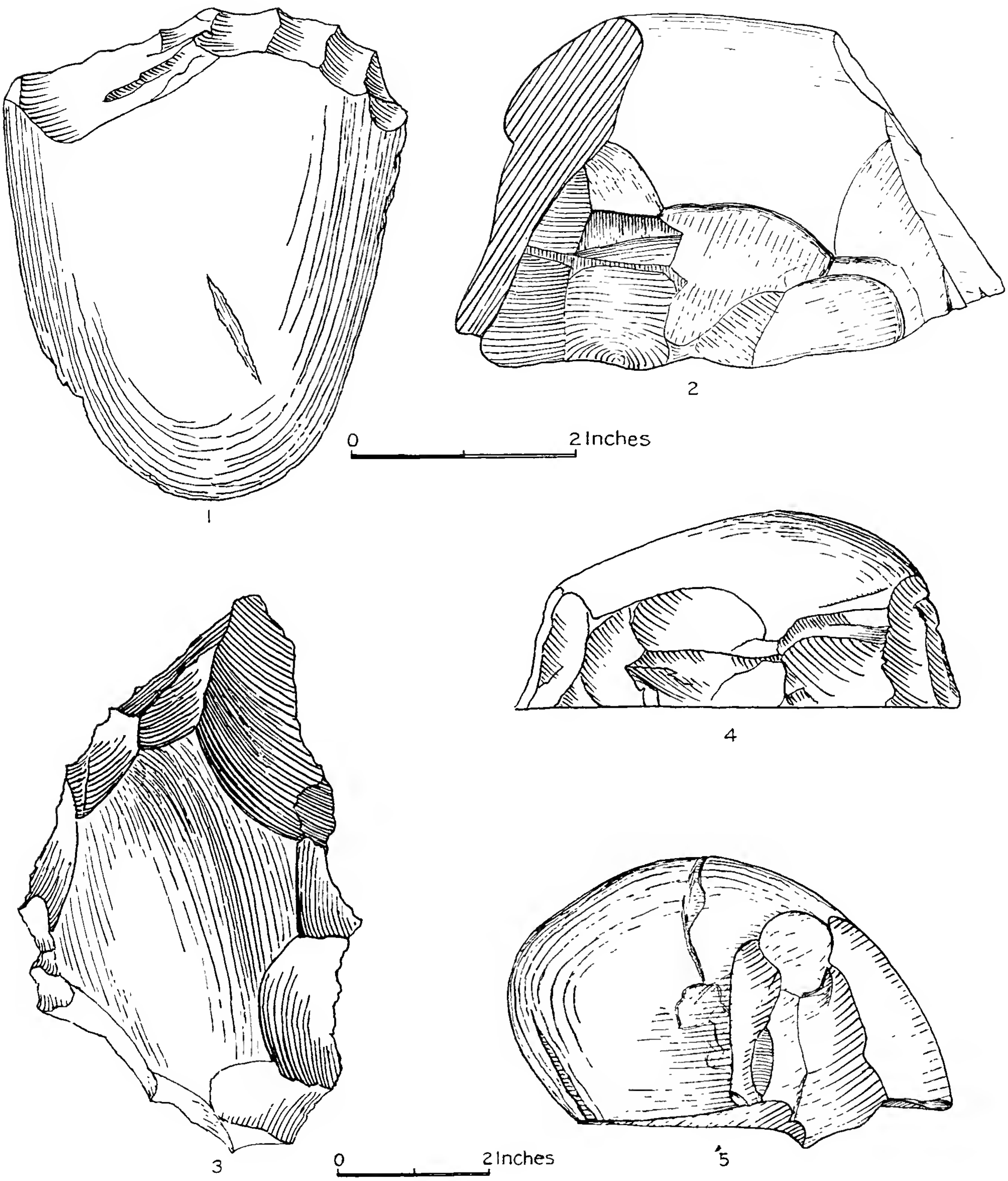
A

B

Paleolithic implements from Narbada Valley. A, rolled Abbevillian hand axe and early Soan chopper from basal gravel; B, late Acheulian cleavers from clay of lower Narbada group.

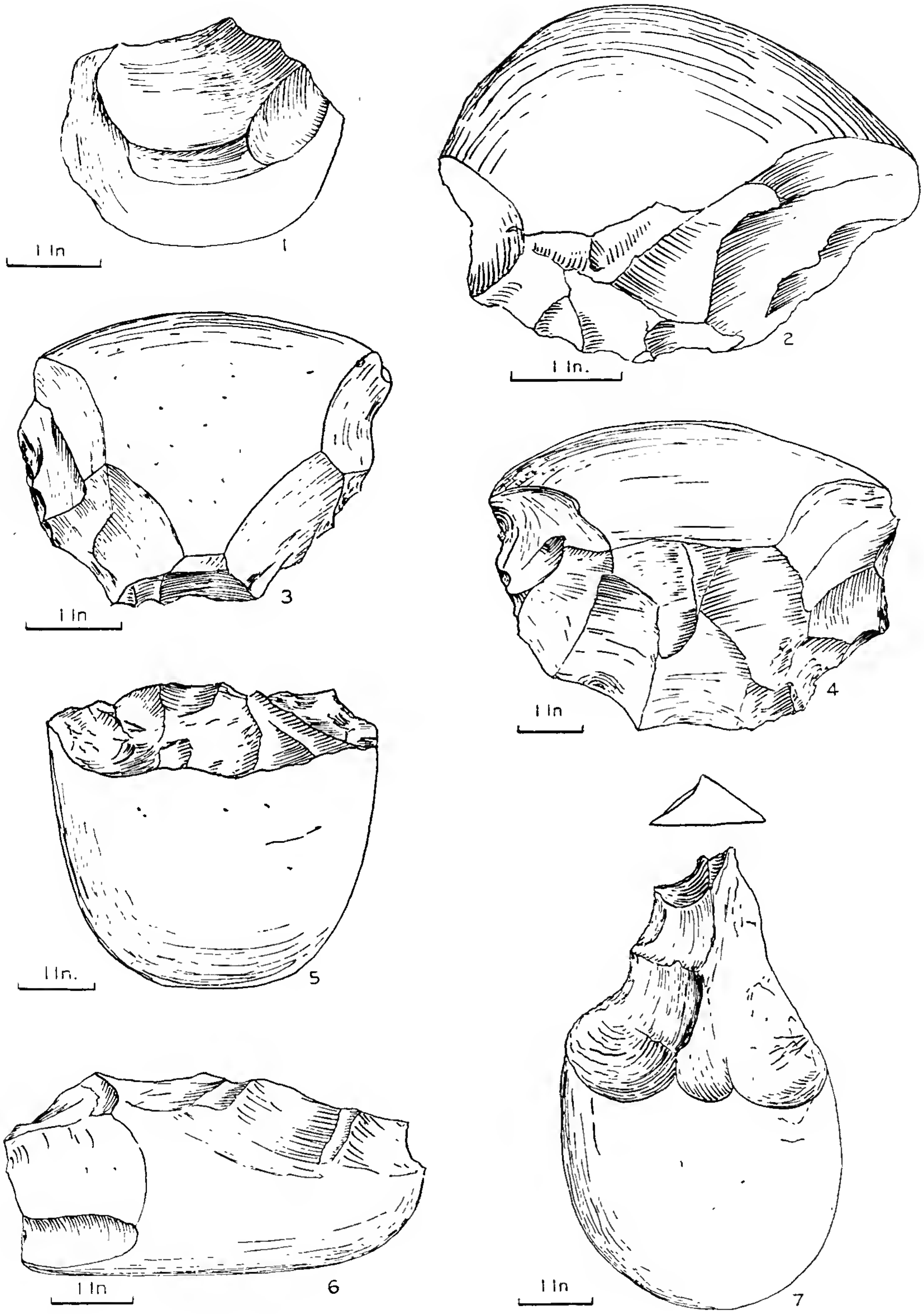


Large flake from the Boulder conglomerate at Kallar



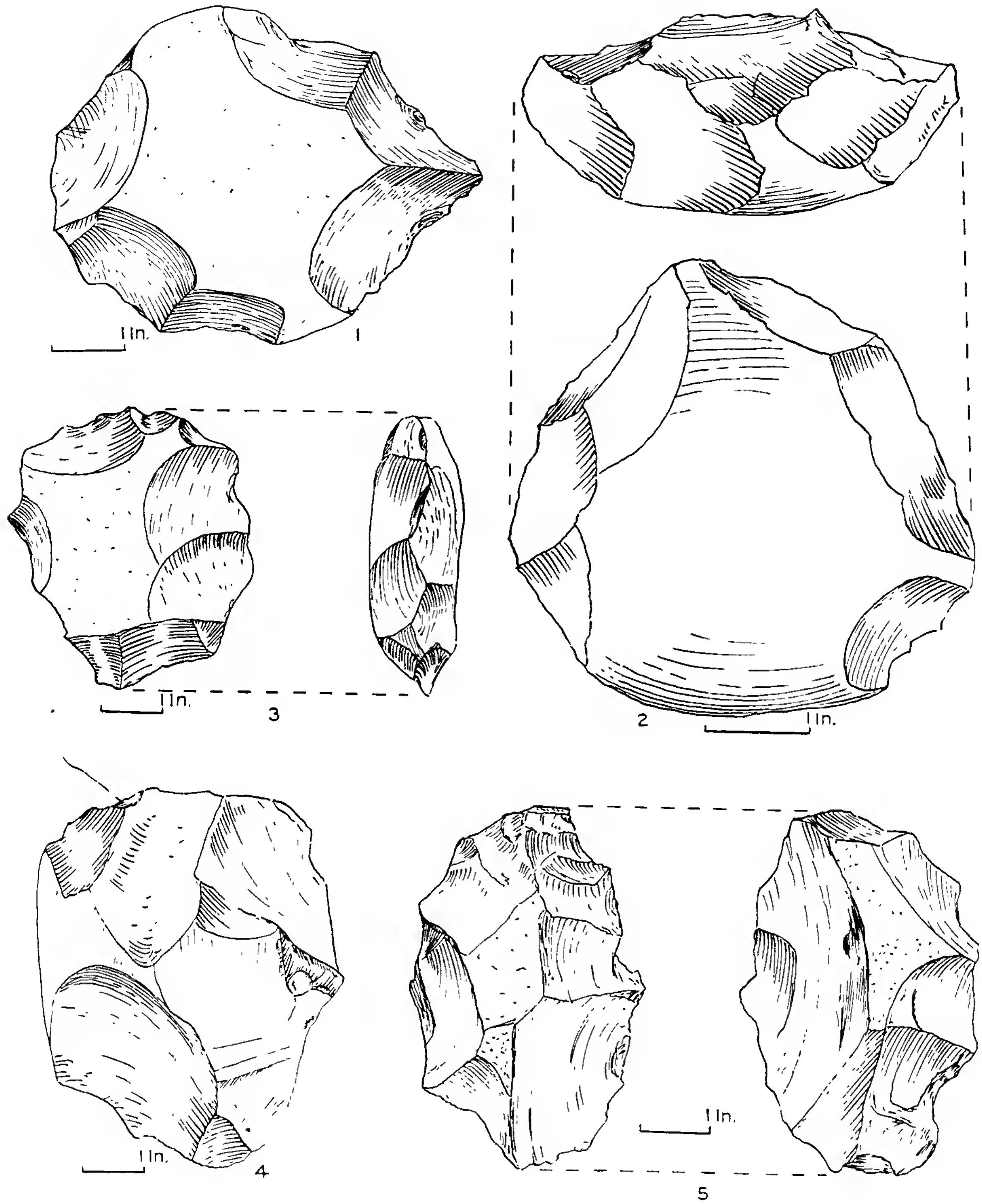
Early Soan pebble tools, flat-based types

No. 1—*a* (i).
No. 4—*a* (ii).
Nos. 2, 3—*a* (iii).
No. 5—*a* (iv).

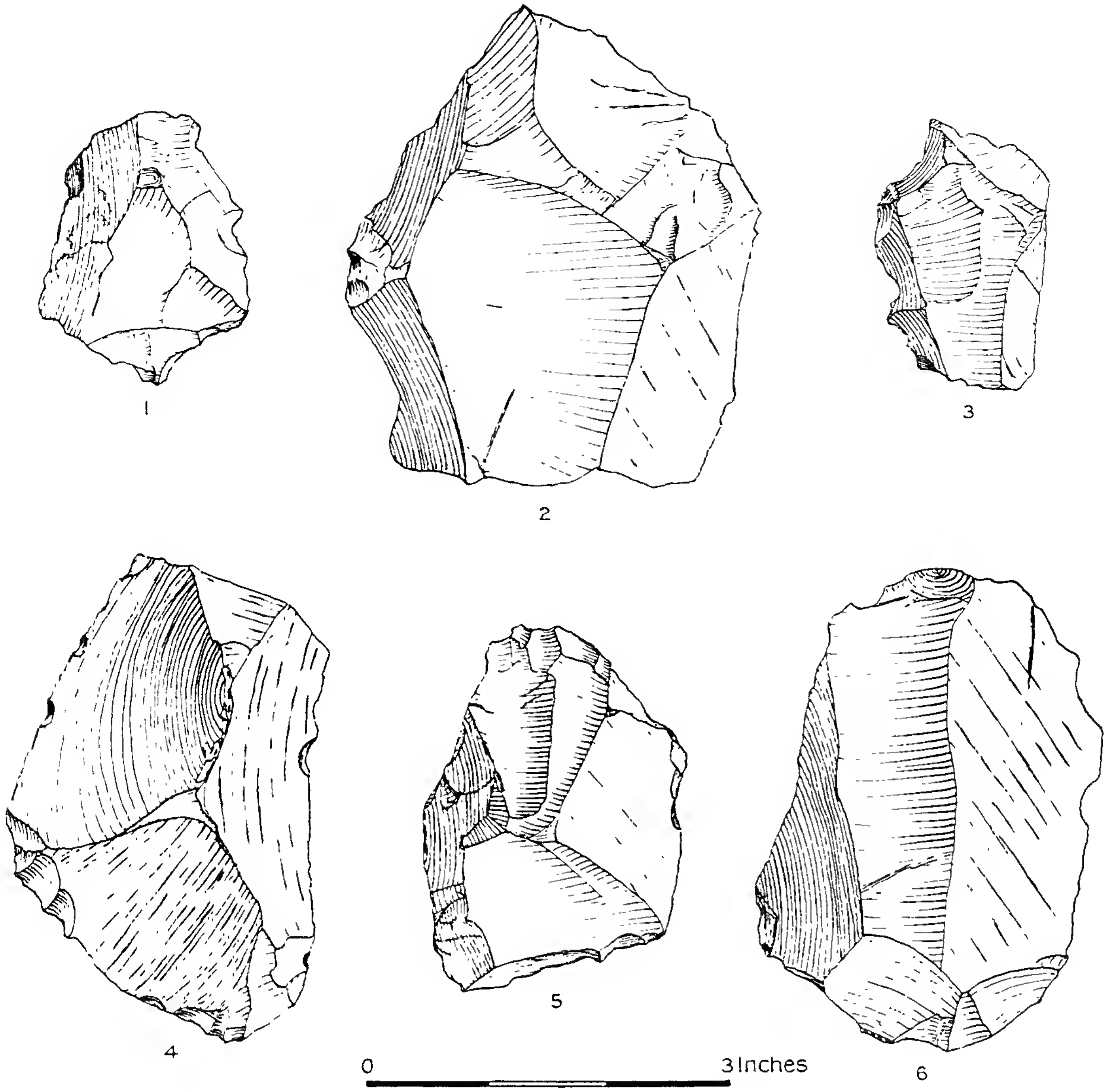


Early Soan pebble tools, rounded-pebble types

No. 1—b (i).
Nos. 2–5—b (ii).
No. 6—b (iii).
No. 7—b (iv).

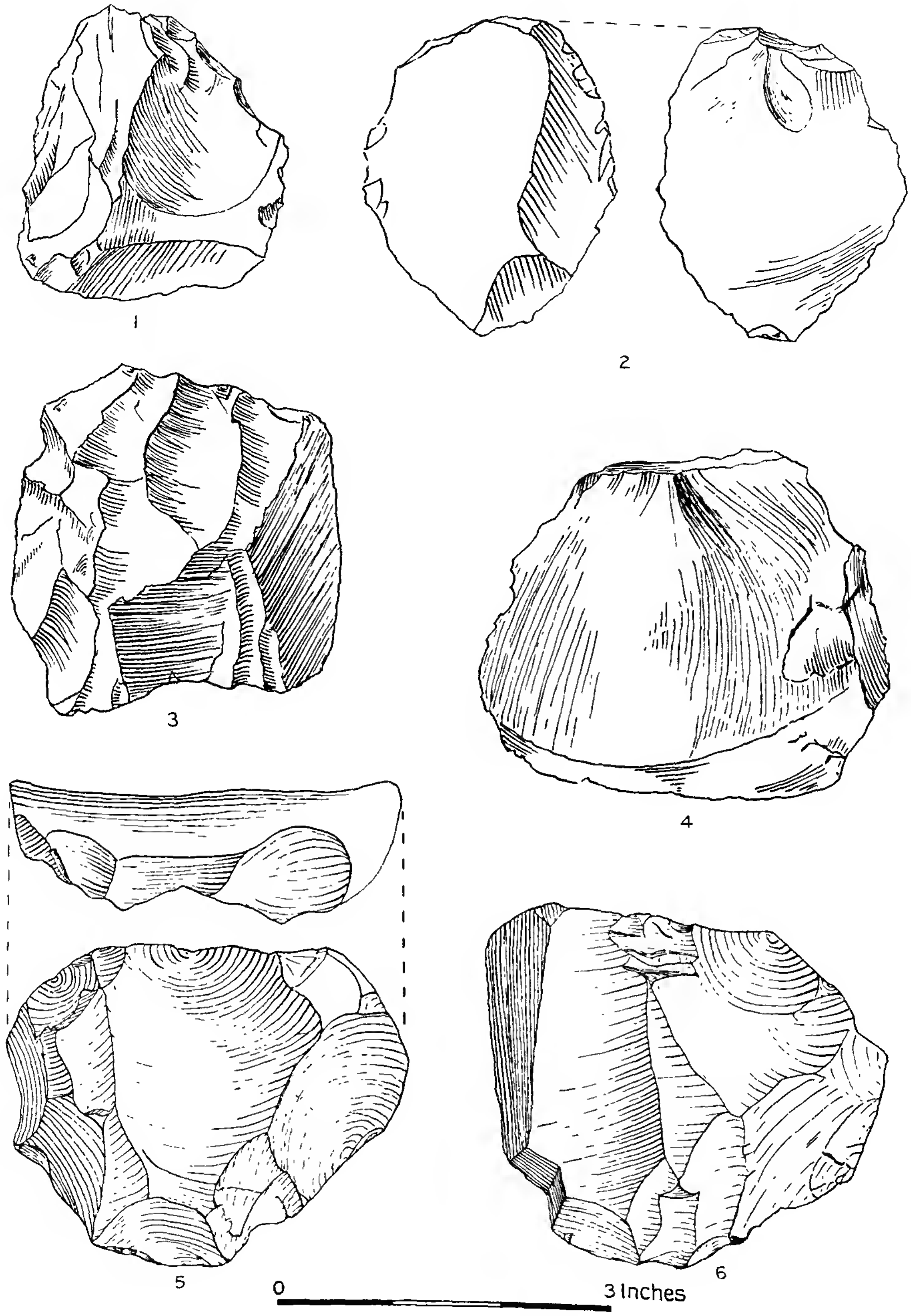


Early Soan cores, discoidal types

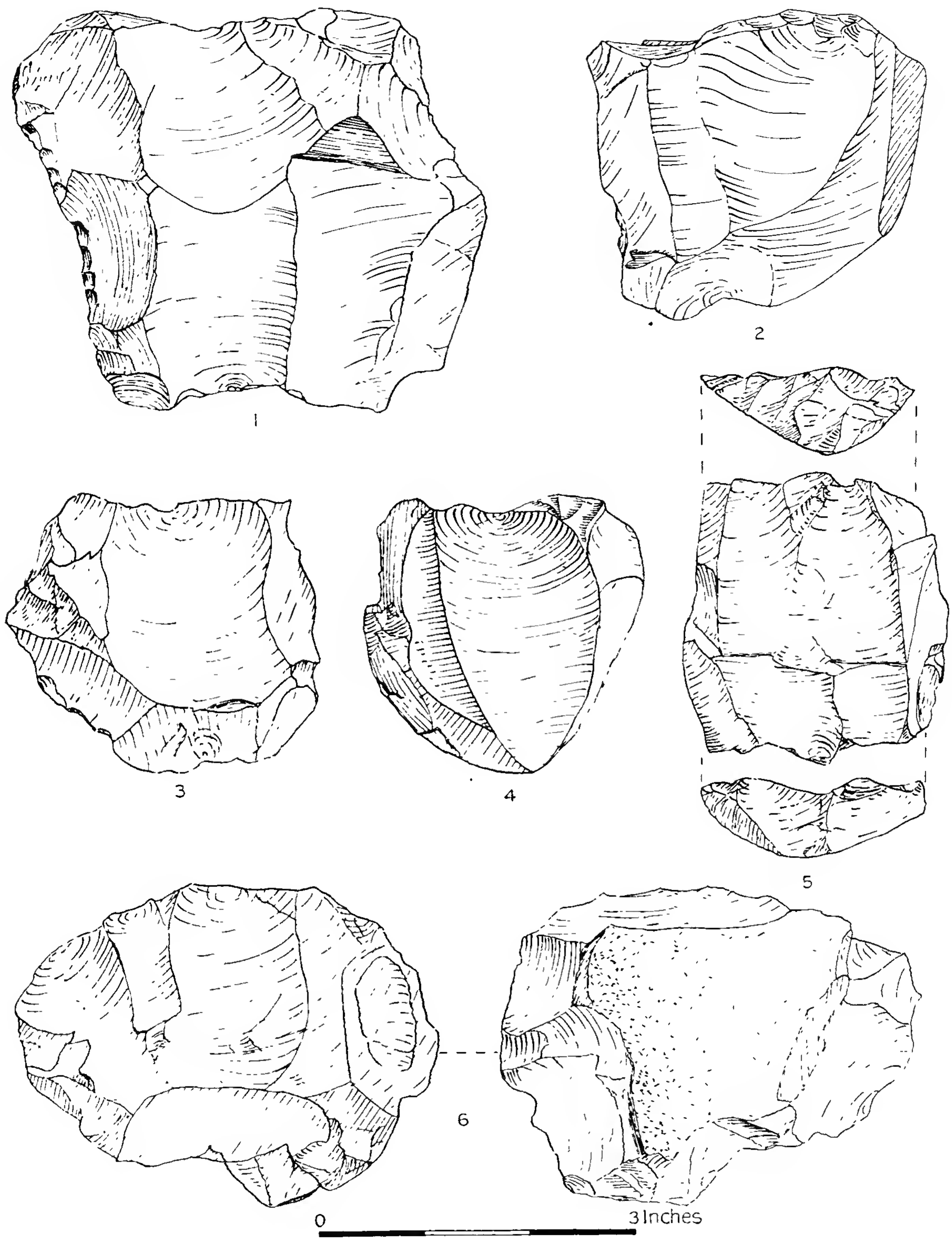


Early Soan flakes

Nos. 1, 2, 3, 4, 6—Early Soan B. No. 5—Early Soan C.

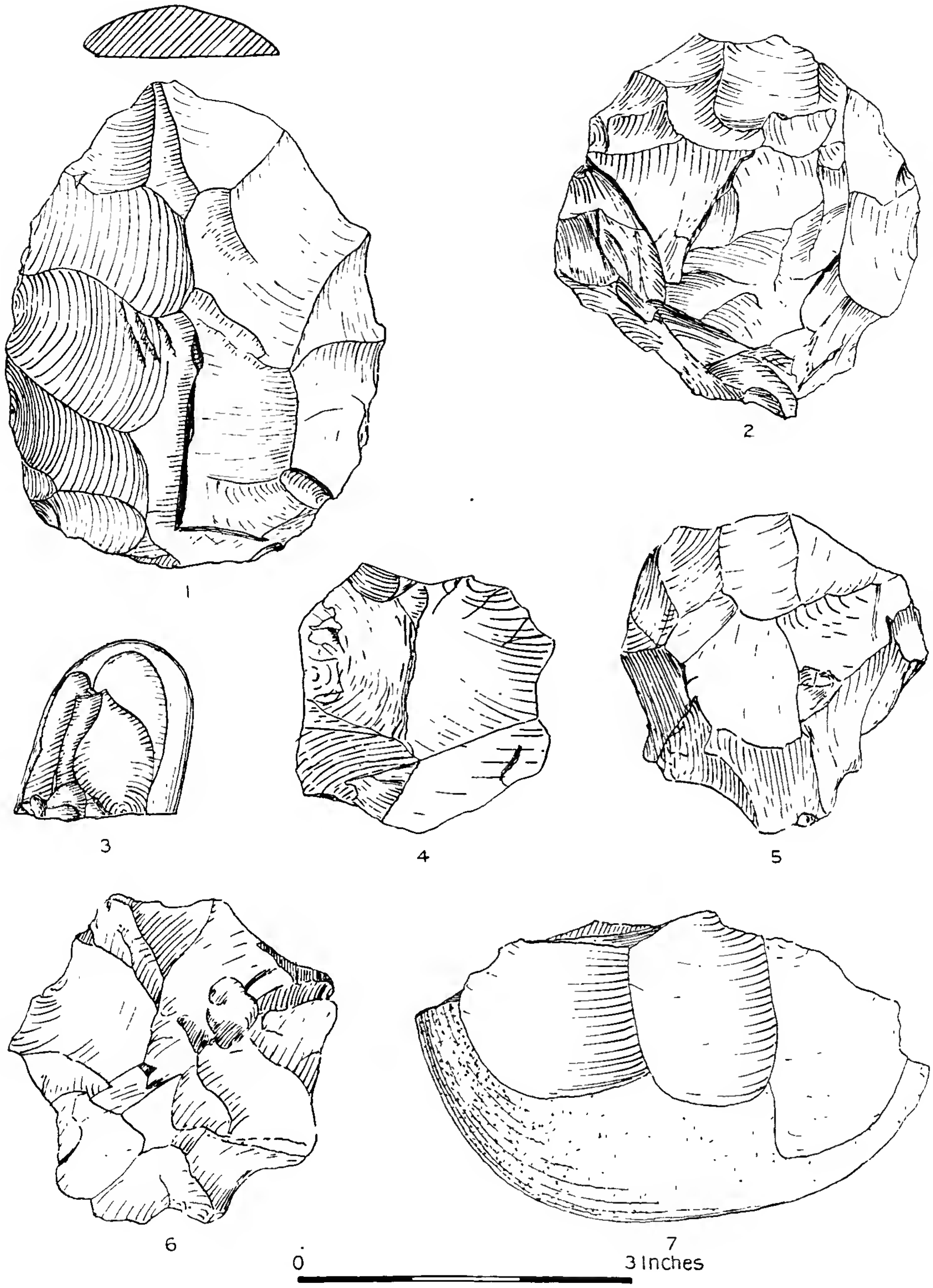


Early Soan C cores and flakes



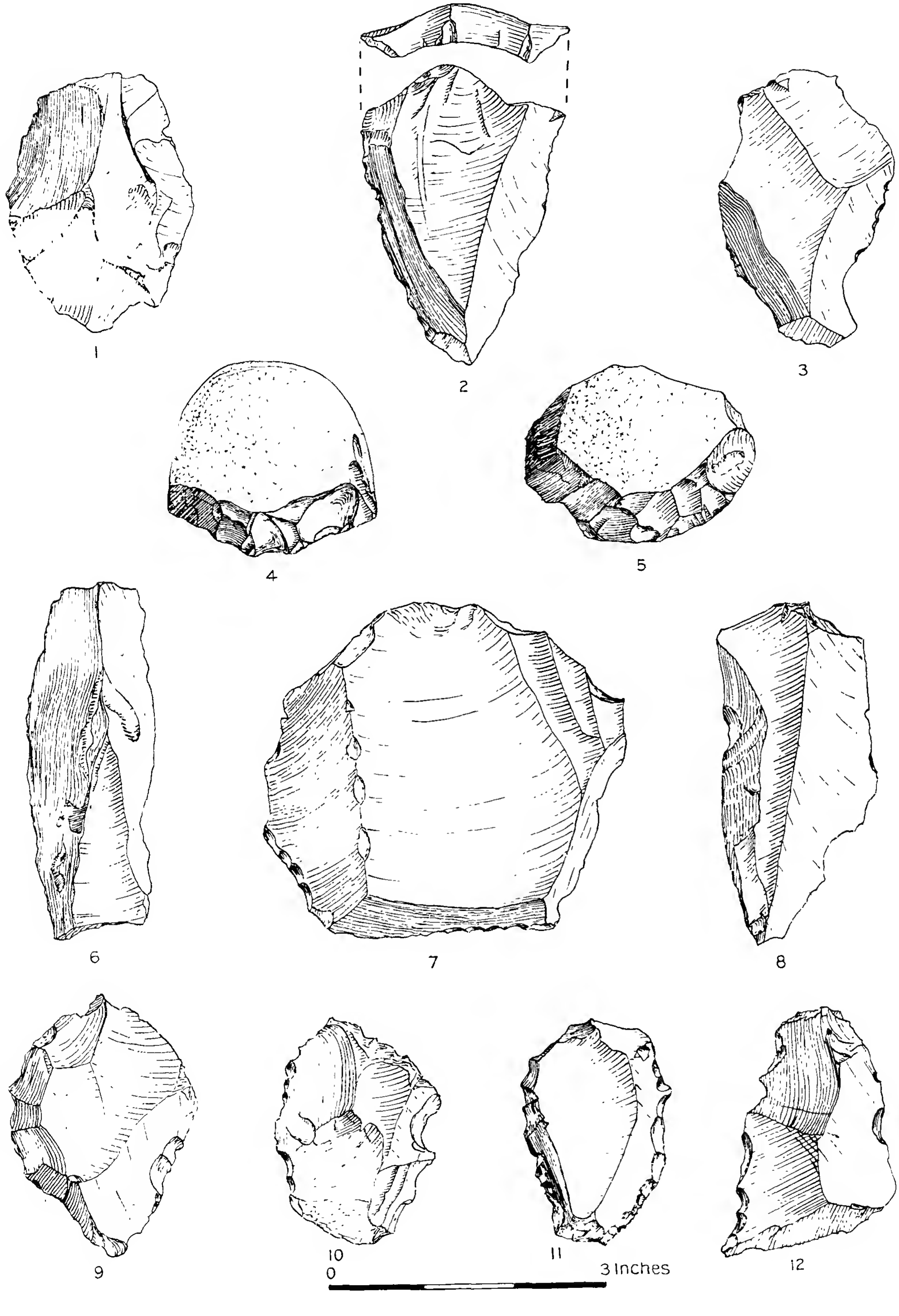
Late Soan A cores

Nos. 1, 2, 3, 5 – type (i). No. 4 – type (ii). No. 6 – type (iii)

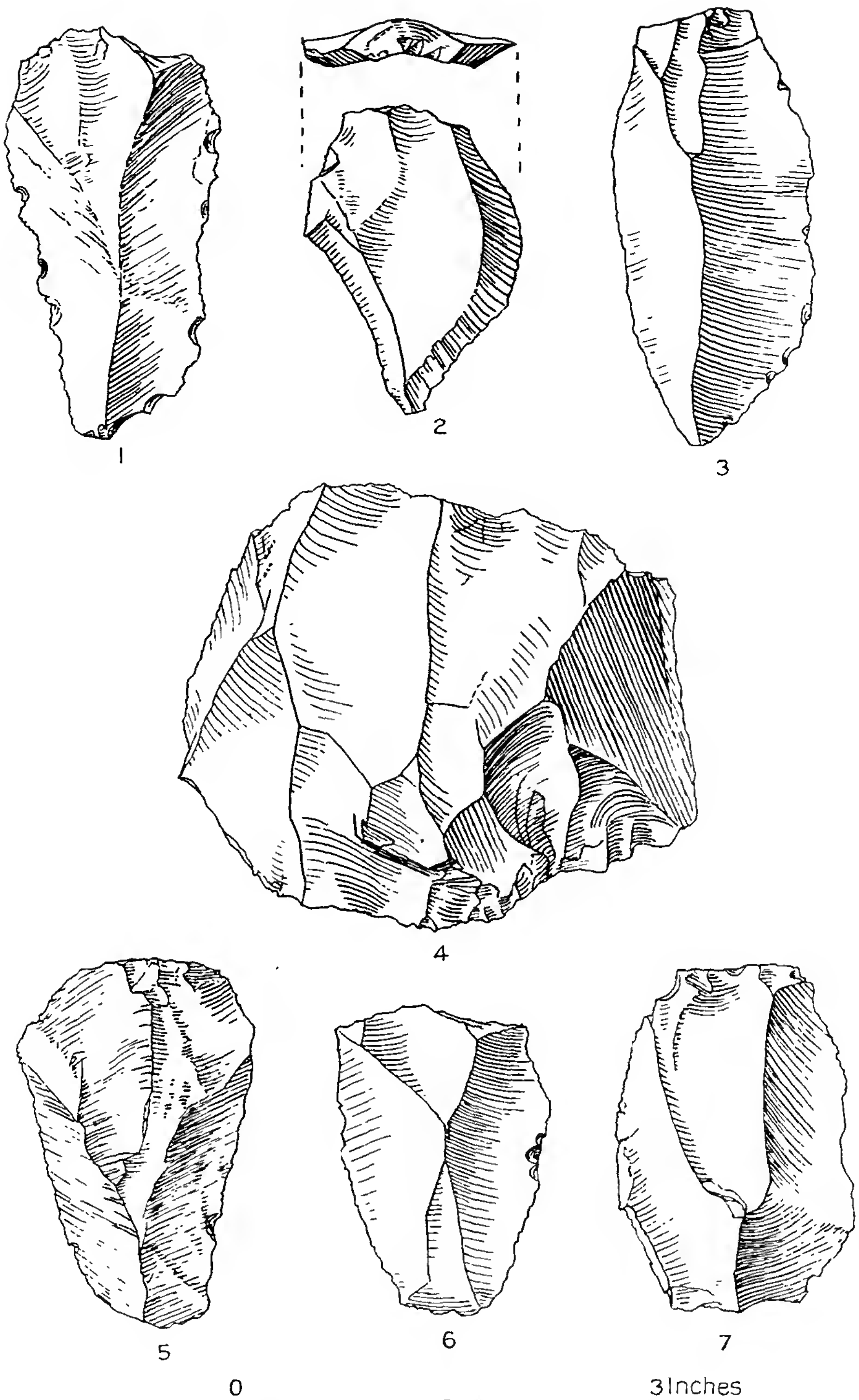


Late Soan A cores

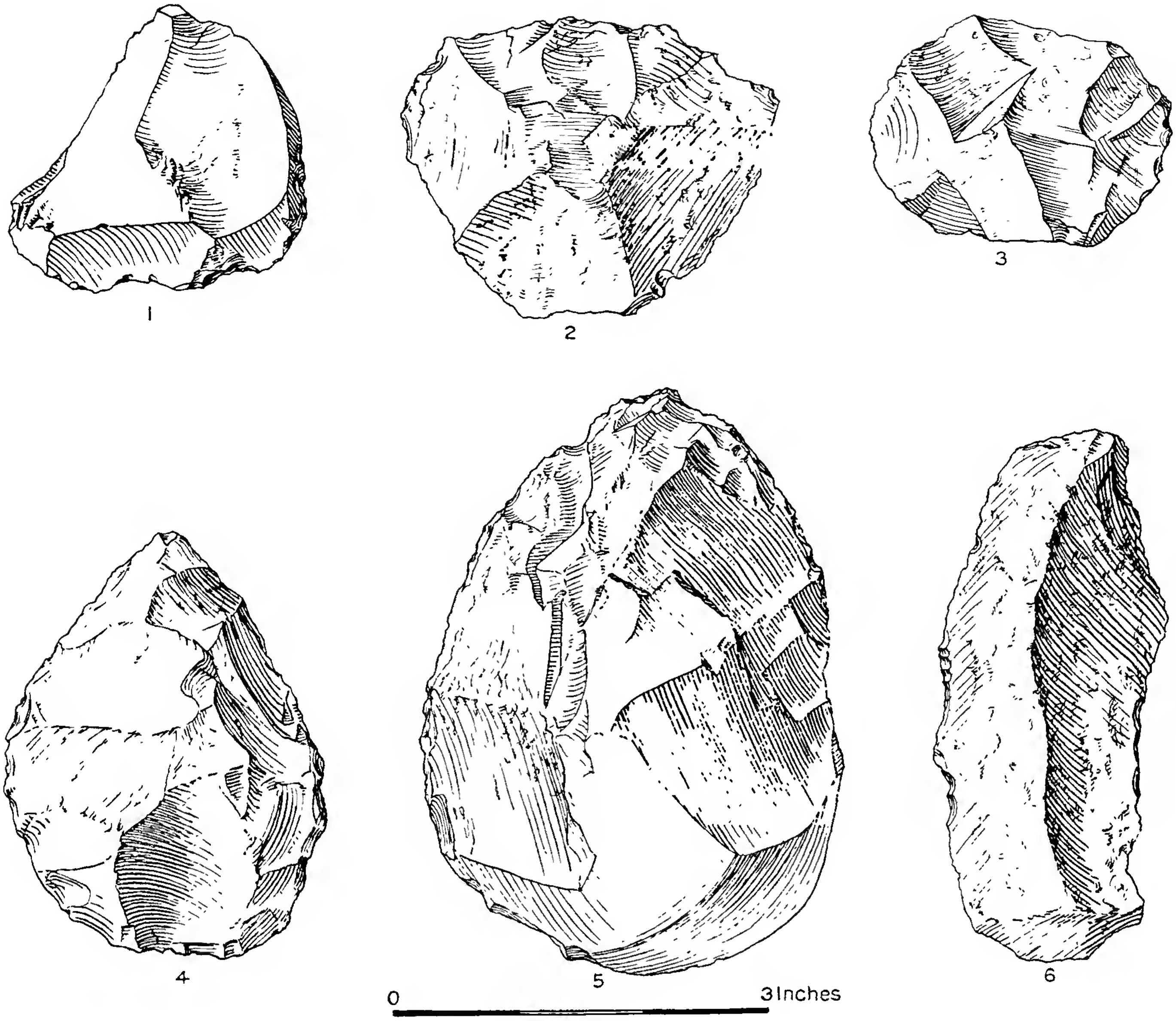
No. 1—type (v).
No. 7—type (vi).
Nos. 2, 4, 5, 6—type (iv).
No. 3—small pebble tool (?).



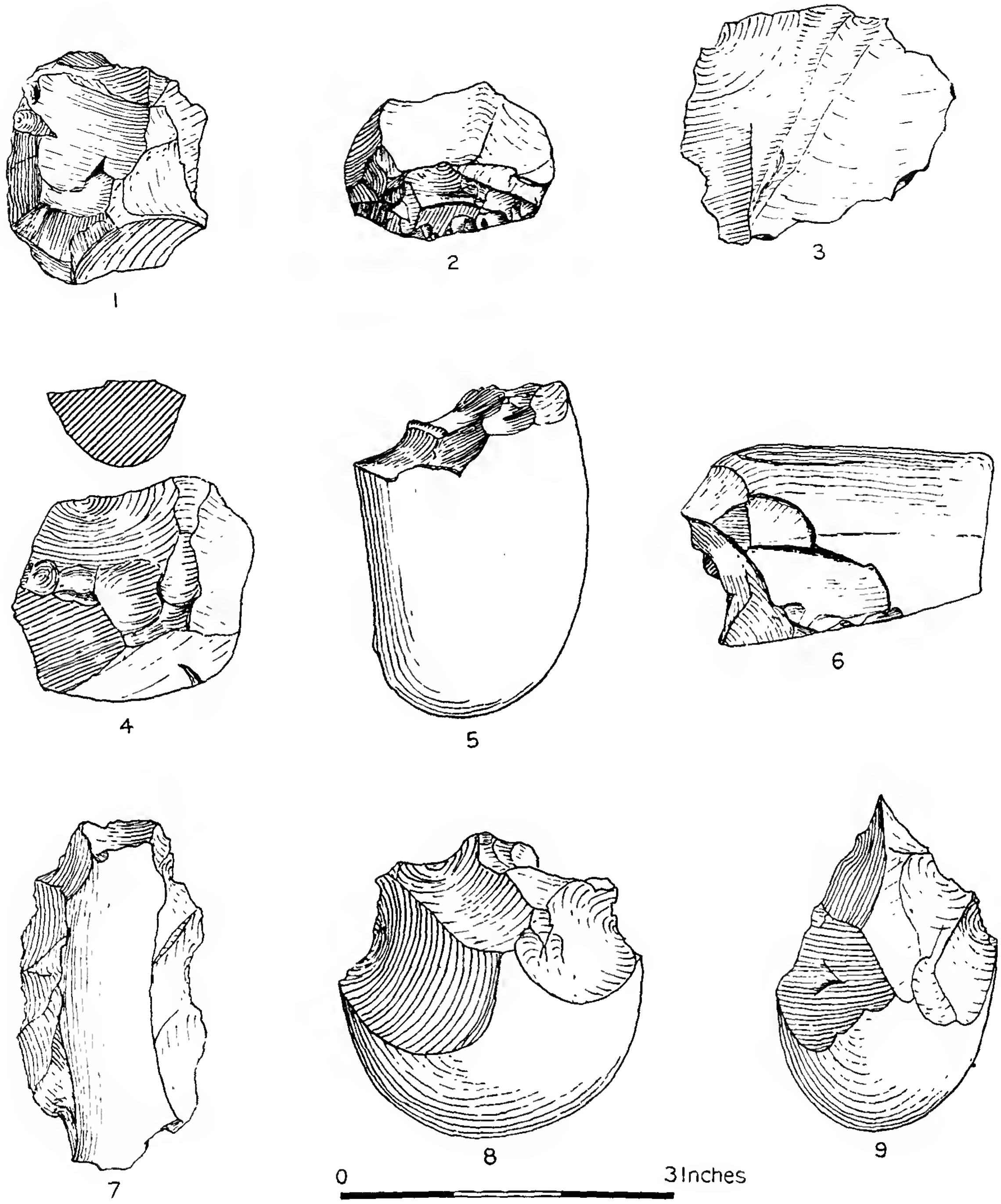
LATE SOAN A FLAKES



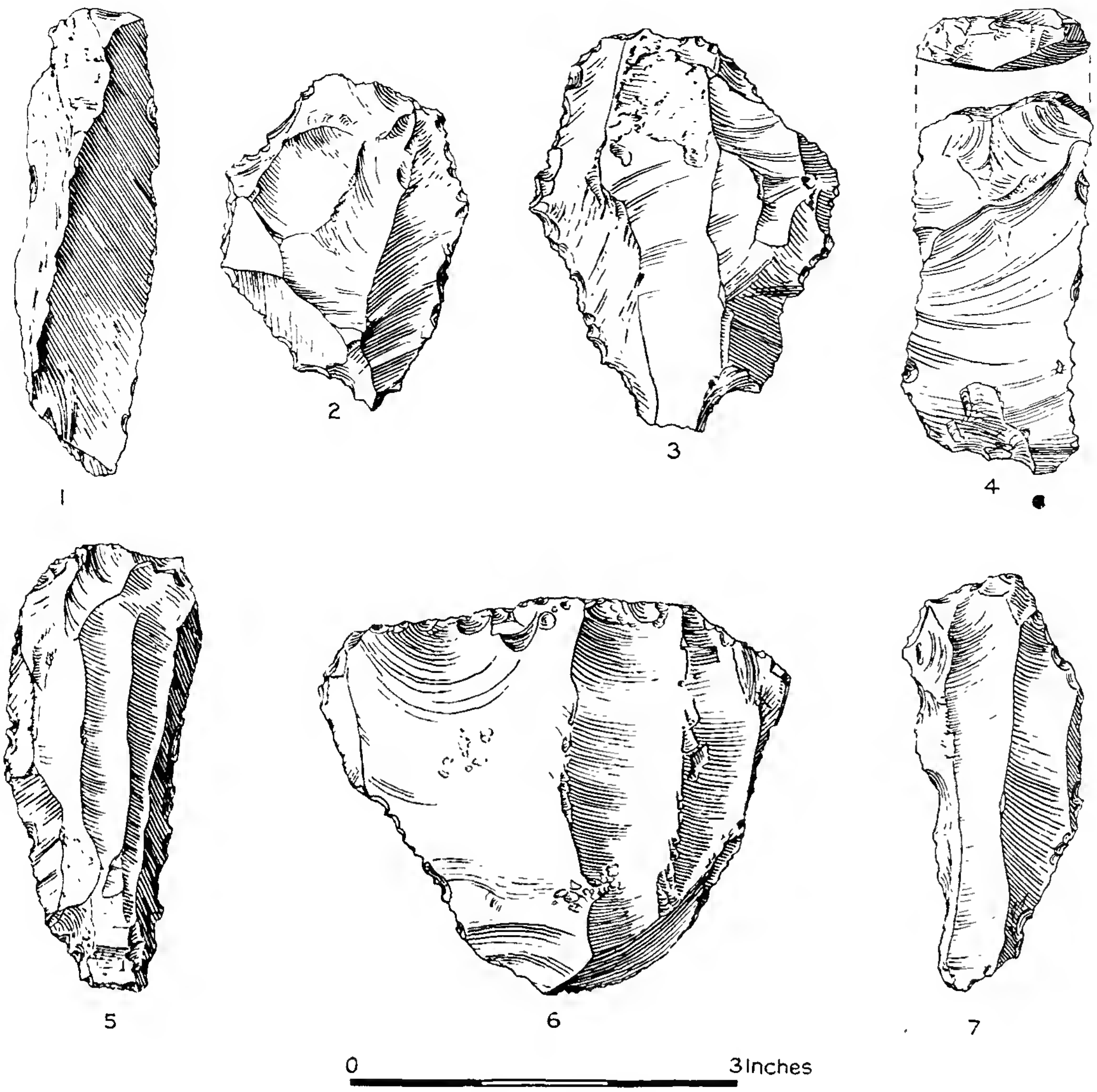
Late Soan B core and flakes



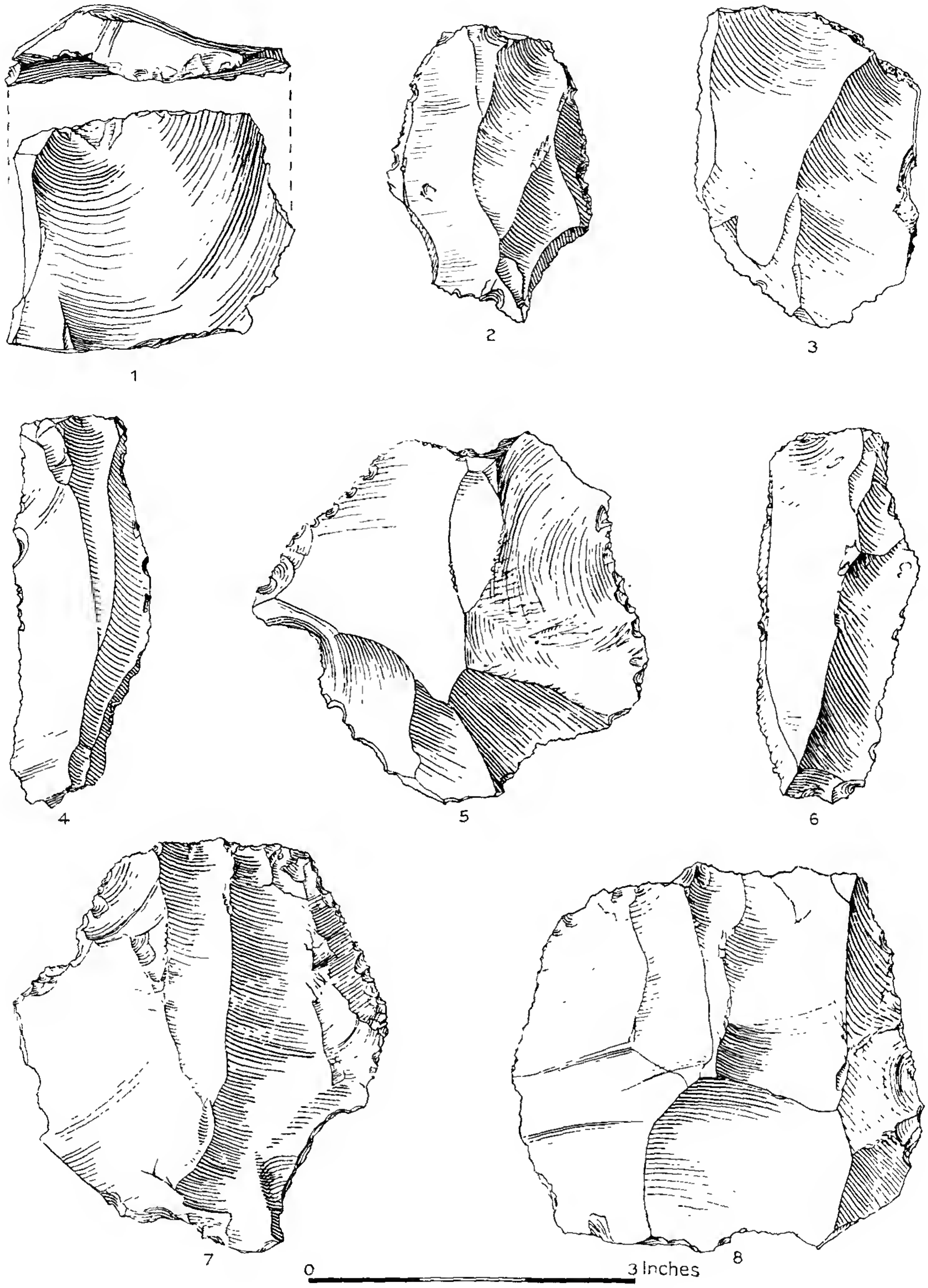
Chauntra industry



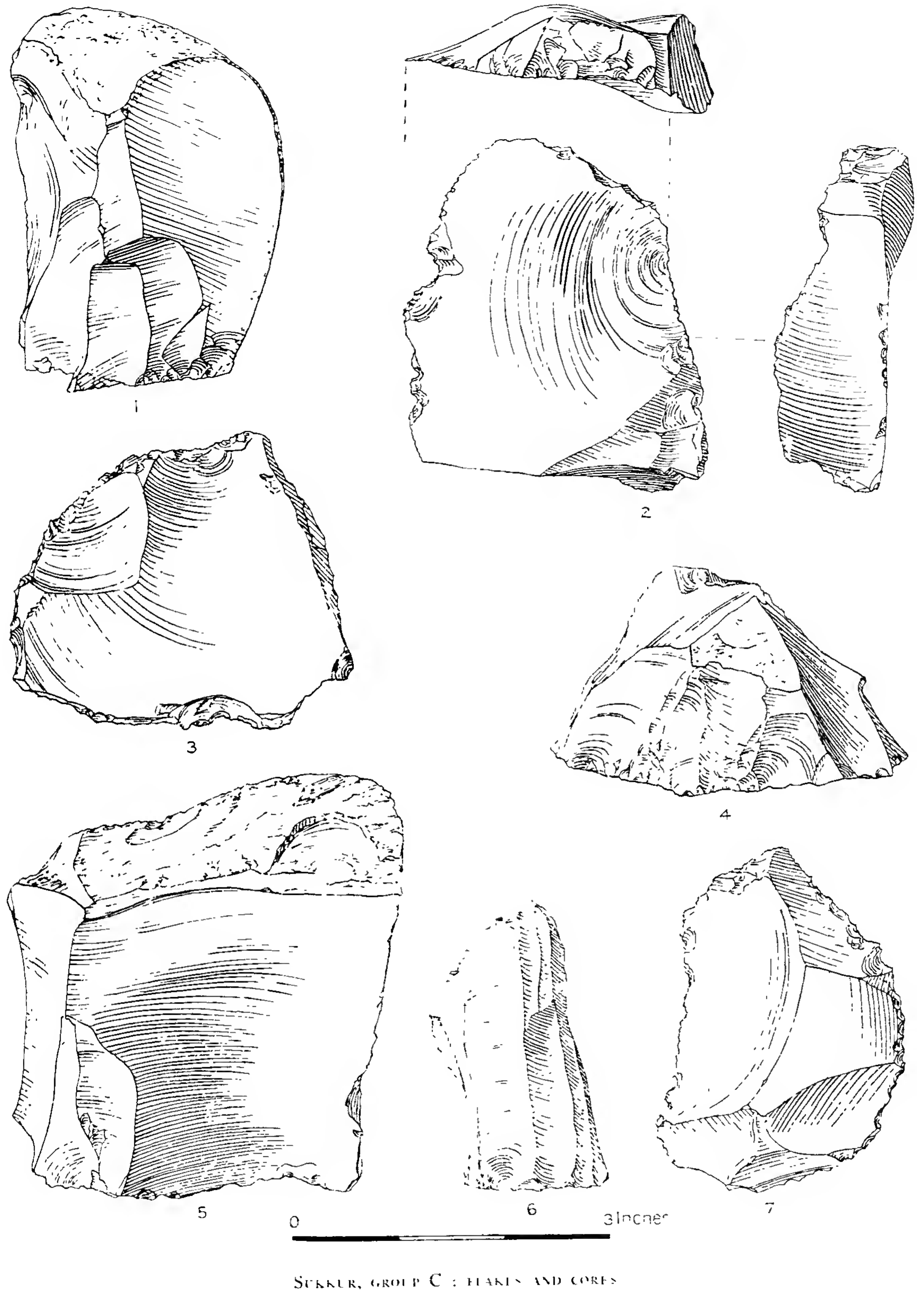
Dhok Pathan industry



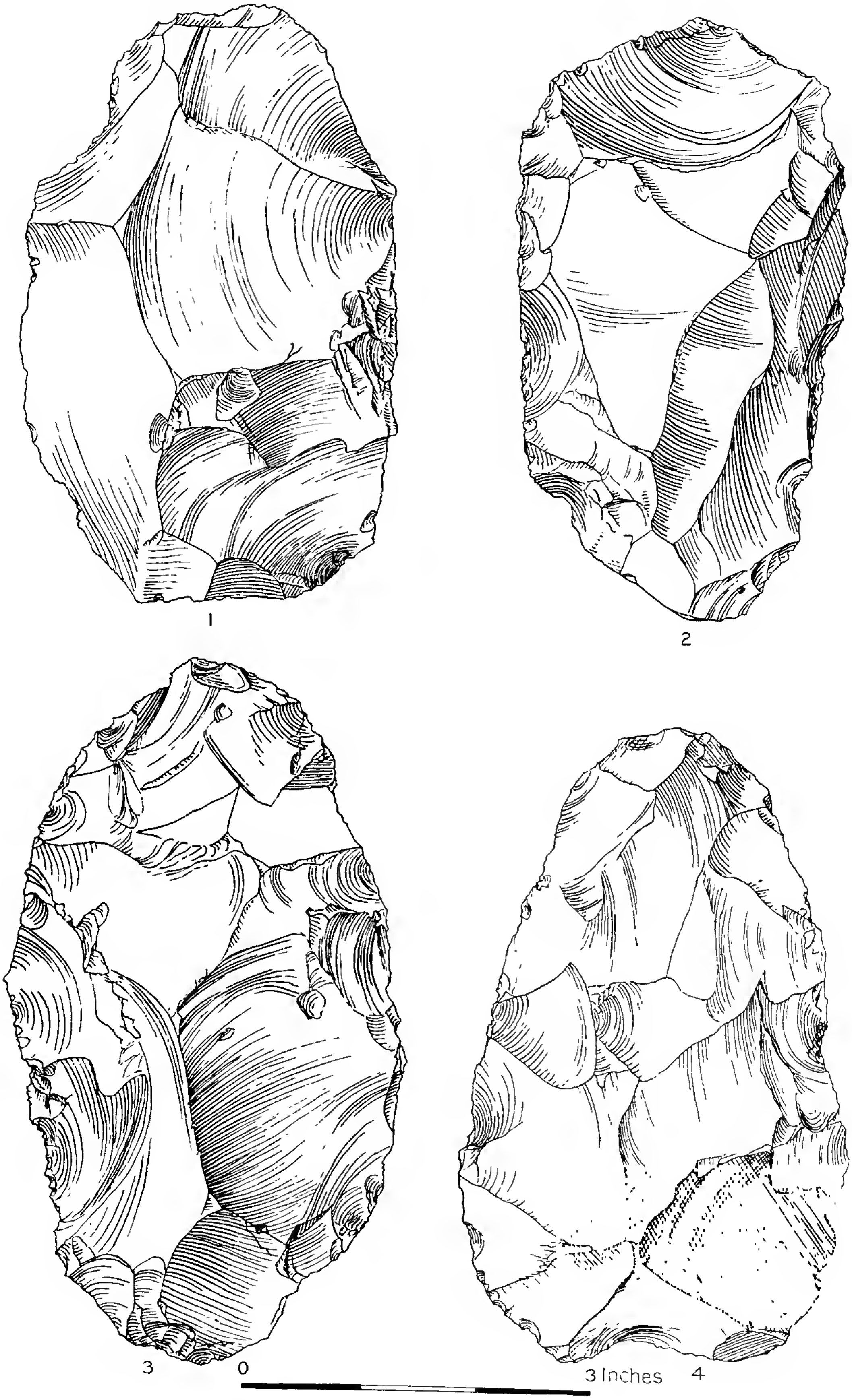
Sukkur, group A: flakes, blades, and core



Sukkur, Group B: flakes, blades, and cores

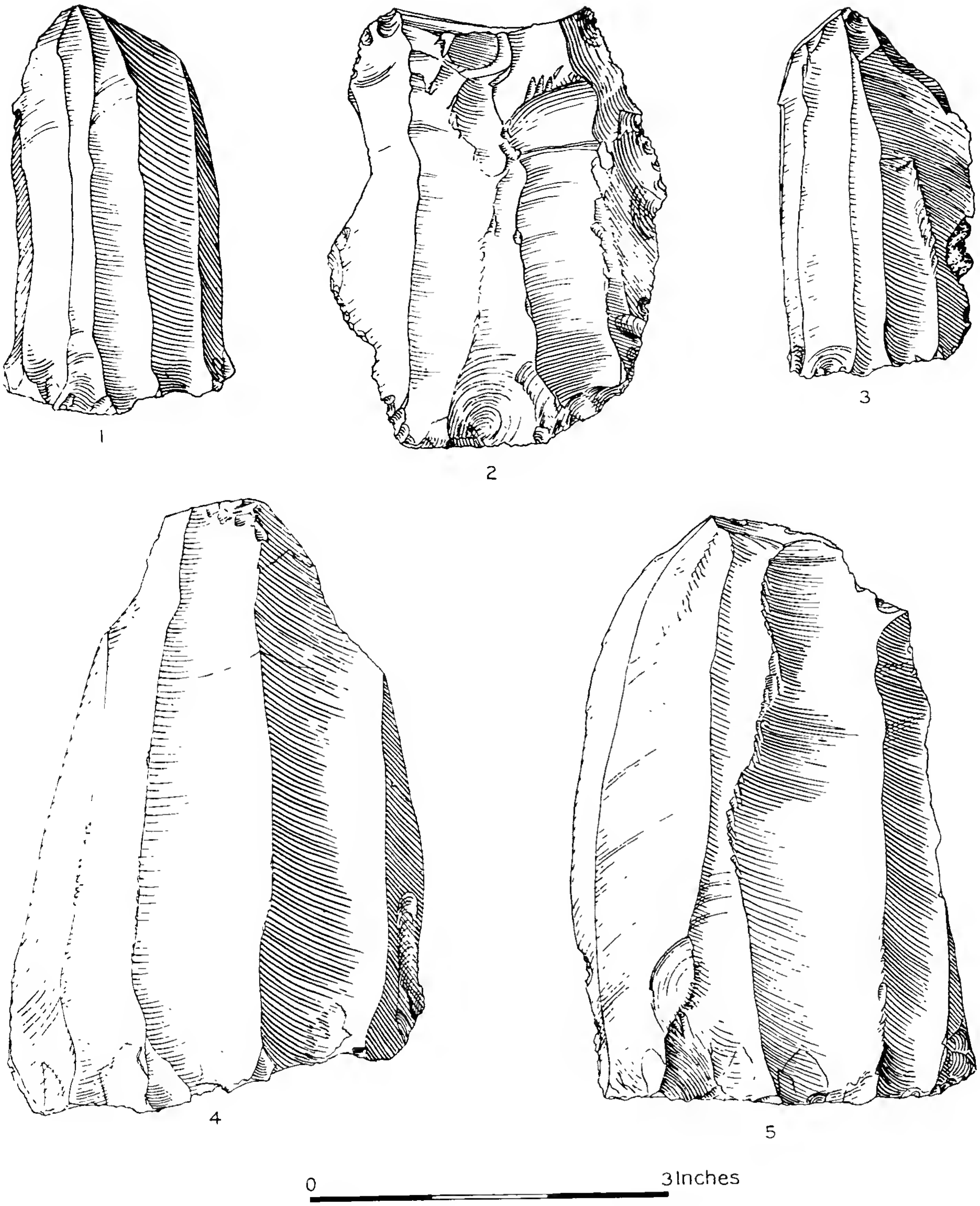


Sukkur, group C : flakes and cores



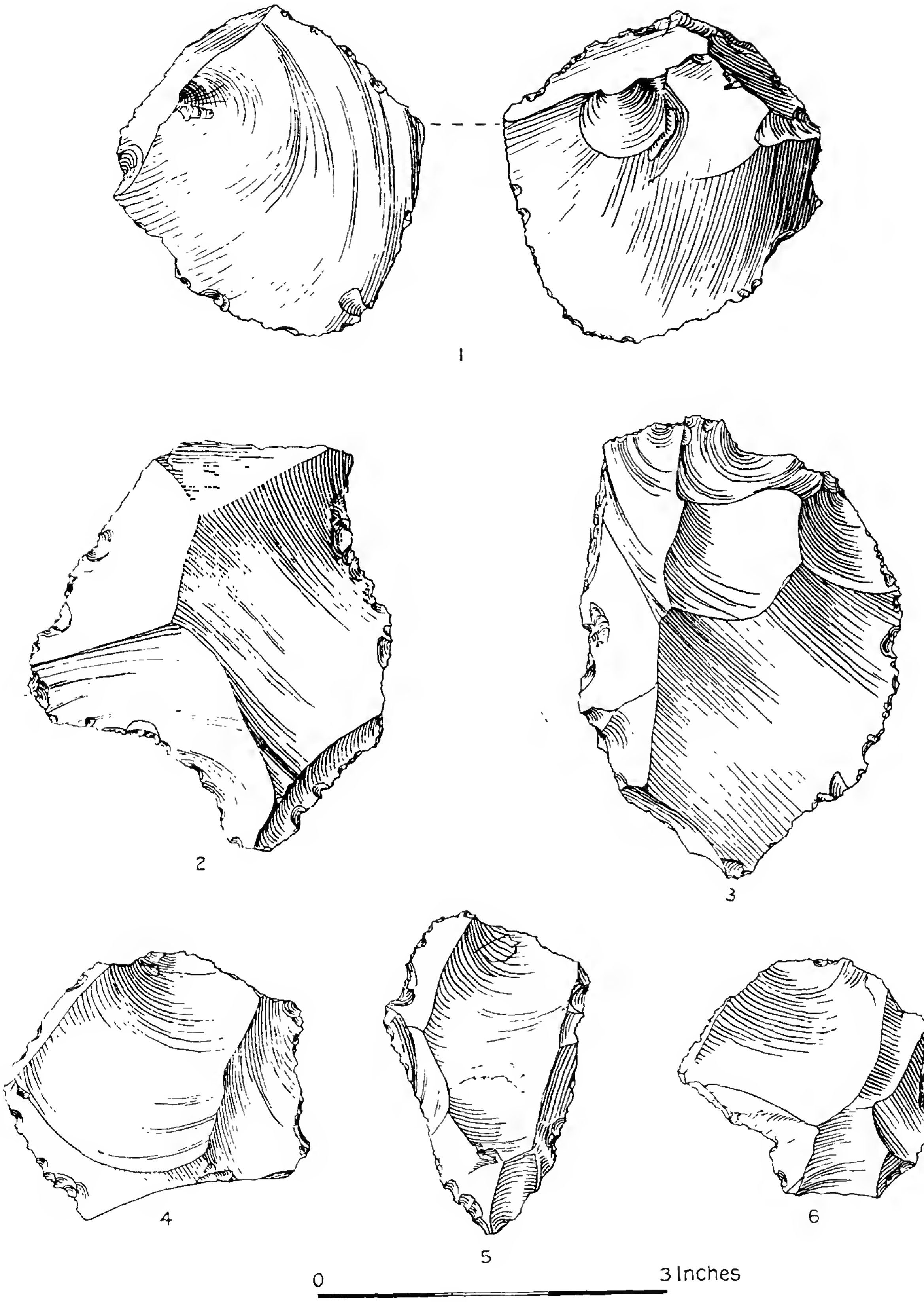
Sukkur, groups B and C: hand-ax type of core

Nos. 1 and 2 are probably true cores, no. 3 shows some signs of retouch, and no. 4 is trimmed to form what is undoubtedly a true implement, closely resembling an Acheulian hand ax.

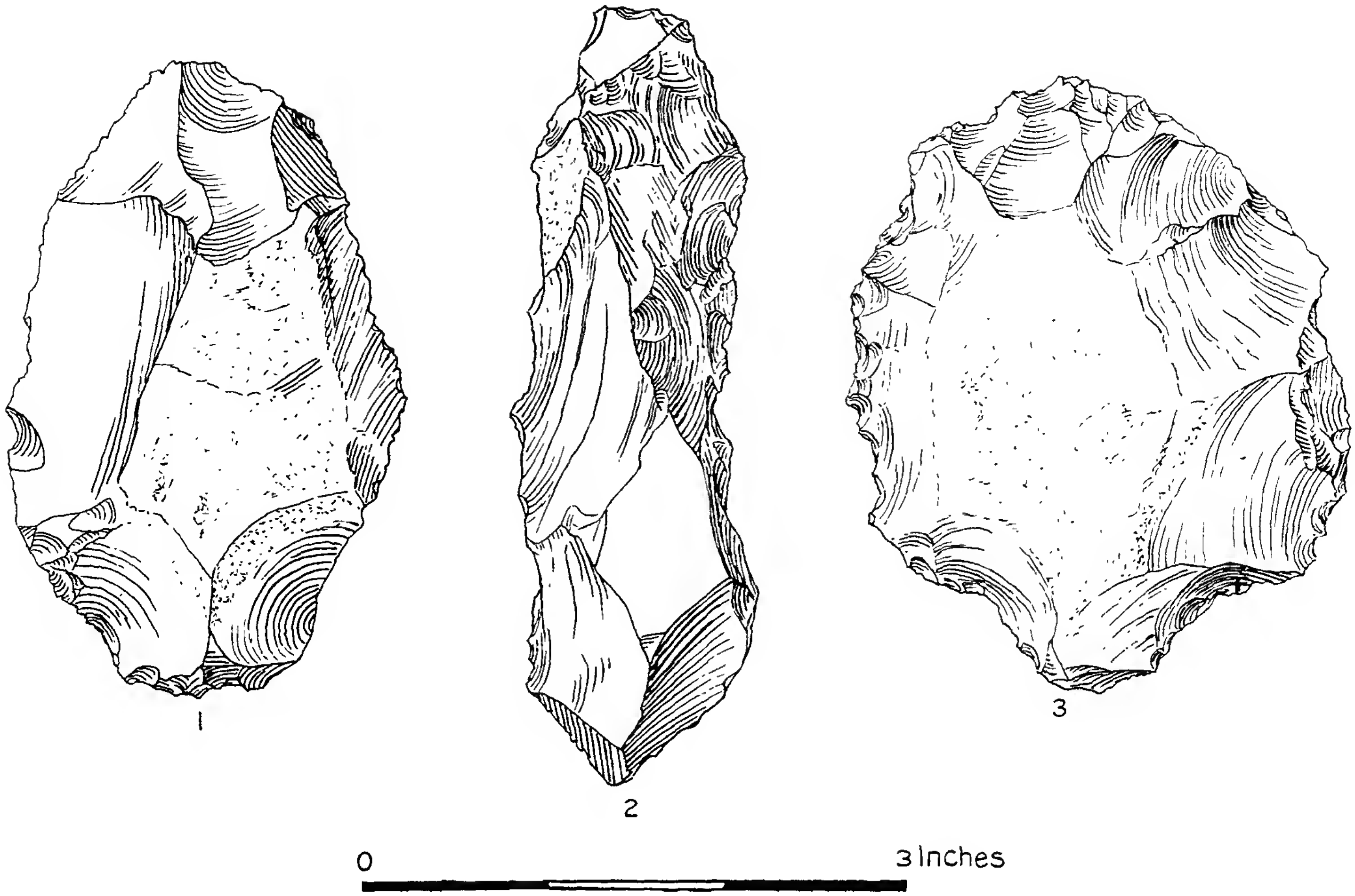


Rohri I : cores and waste flake

ROHRI I : BLADES



ROHRI 2 . FLAKES



Rohri 2: cores and picklike implement

PLATE LIII

Fossil plants from interglacial Karewa clays, Kashmir

1. *Betula utilis* D. Don. Laradura.
2. *Alnus nepalensis* D. Don. Ningle Nullah.
3. *Desmodium latifolium* DC. Laradura.
4. *Prunus cornuta* Wall. Ningle Nullah
5. Cone of *Betula* sp × 5. Laradura

6a, c. *Quercus ilex* L. *a*, Dangarpur; *c*, Laradura.

6b. *Quercus semecarpifolia* Smith. Laradura.

7. *Quercus incana* Roxb Laddarmarg
8. *Sageretia oppositifolia* Brongn. Ningle Nullah.
9. *Quercus ilex* L. Laradura.
10. *Quercus glauca* Thunb. Bota Pathri, Dr Sahni's collection.

(For explanation see opposite page.)

PLATE LIV

FOSSIL PLANTS FROM INTERGLACIAL KAREWA CLAYS, KASHMIR

1. *Rhamnus triquetra* Wall. Liddarmarg.
2. *Quercus semecarpifolia* Smith. Dangarpur.
3. *Quercus dilatata* Lindl. Liddarmarg.
4. Indet. new species, not in the present Kashmir flora. Gogajipathar.
5. Same, × 5.
6. *Aesculus indica* Colebr. Ningle Nullah.
7. *Quercus dilatata* Lindl. Laradura.
8. *Berberis ceratophylla* G. Don. × 5. Liddarmarg.
9. *Salix wallichiana* Anders. Ningle Nullah.
10. Same, × 5.

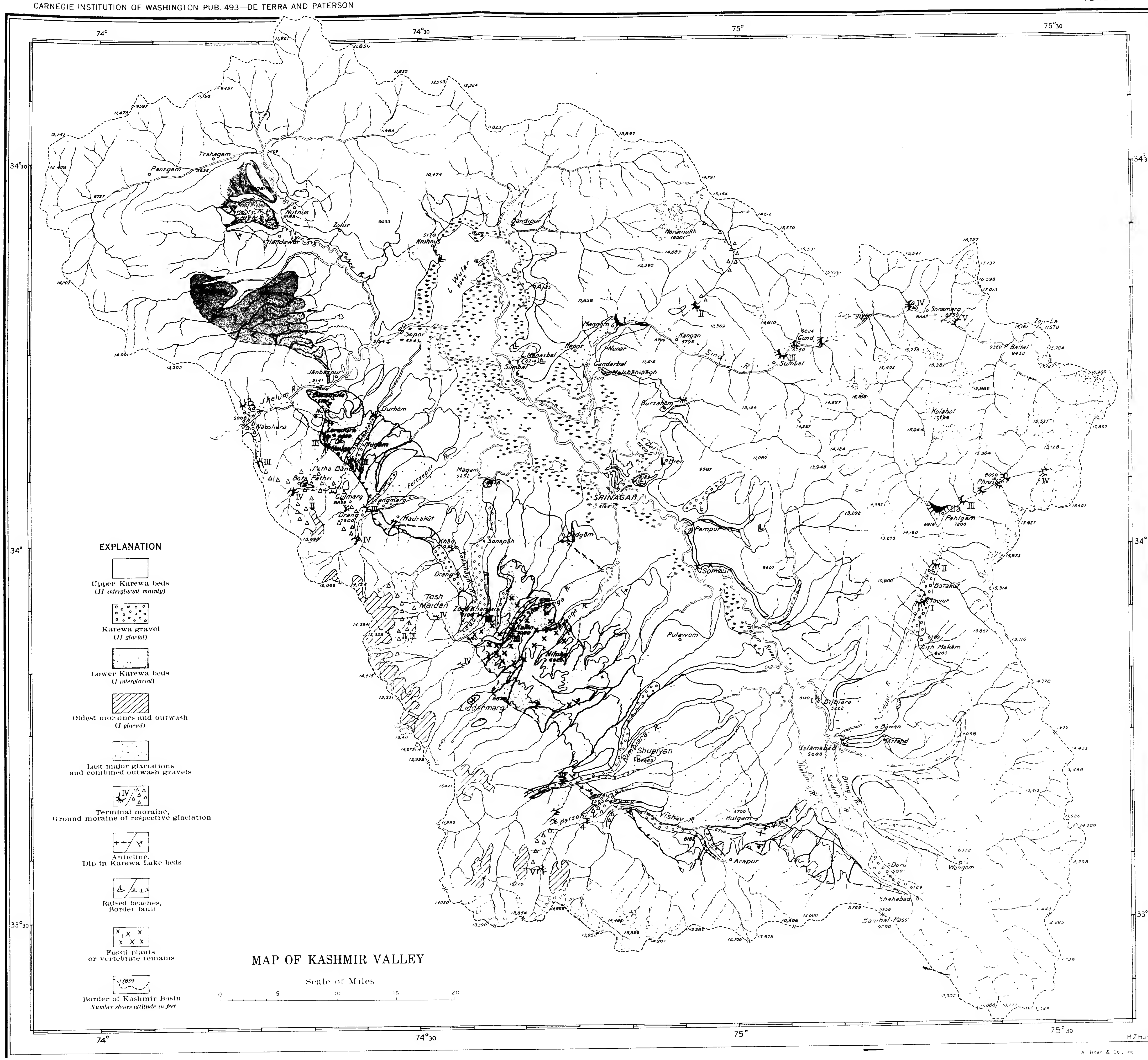
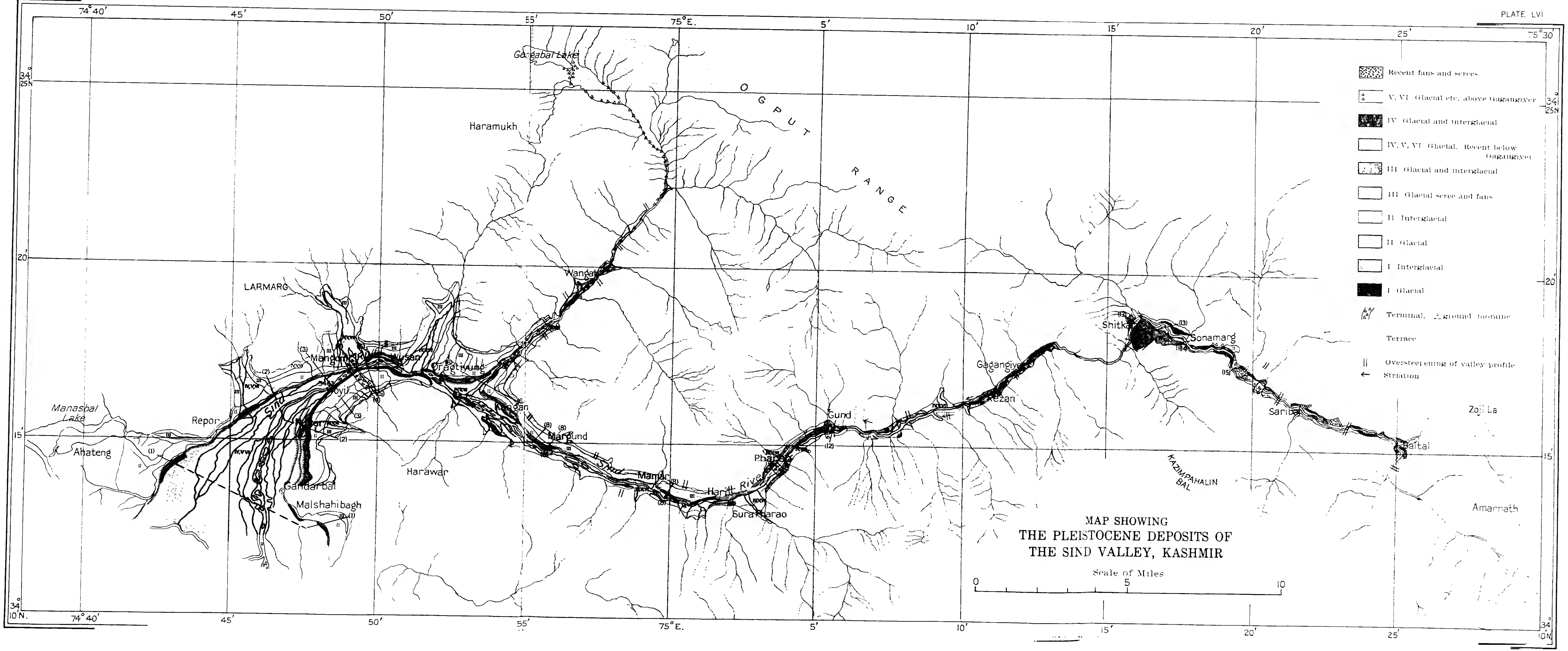
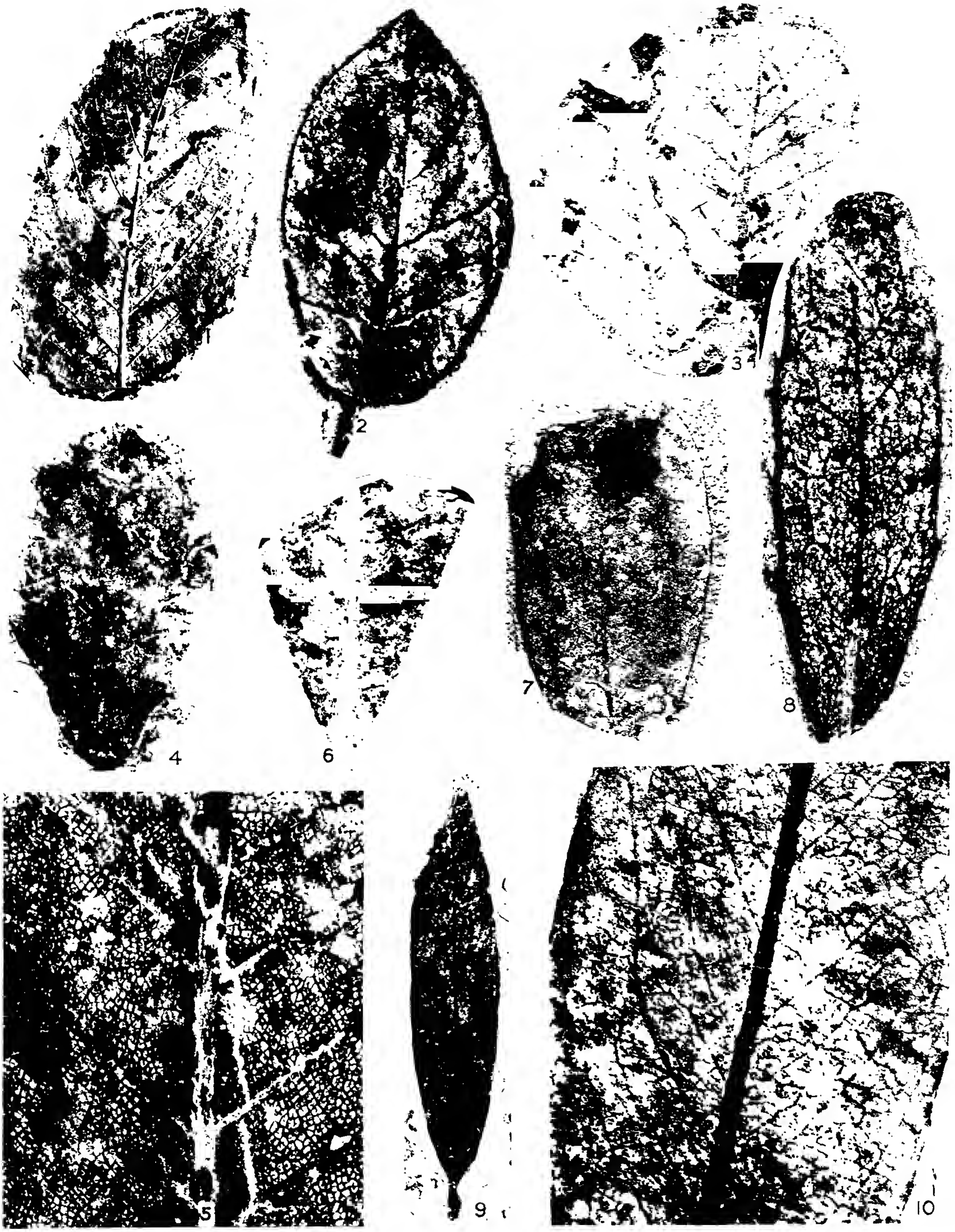

MAP OF KASHMIR VALLEY
Scale of Miles
0 5 10 15 20
EXPLANATION
Upper Karewa beds
(II interglacial mainly)
Karewa gravel
(II glacial)
Lower Karewa beds
(I interglacial)
Oldest moraines and outwash
(I glacial)
Last major glaciations
and combined outwash gravels
Terminal moraine,
Ground moraine of respective glaciation
Anticline,
Dip in Karewa Lake beds
Raised beaches,
Border fault
Fossil plants
or vertebrate remains
Border of Kashmir Basin
Number shows altitude in feet
SRINAGAR
L. Wular
Sopor
Jhelum R.
Sind R.
Gulmarg
Shupiyan
Pahlgam
Islamabad
Banihal Pass
Sonamarg
Zoji-La
74°
74°30
75°
75°30
34°30
34°
33°30
H. Z. Hunt
A. Hoen & Co. Inc.

PLATE LVI



MAP SHOWING
THE PLEISTOCENE DEPOSITS OF
THE SIND VALLEY, KASHMIR



(For explanation see opposite page.)